Physics 20

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Module 8
MECHANICAL WAVES

Rocky View School Division

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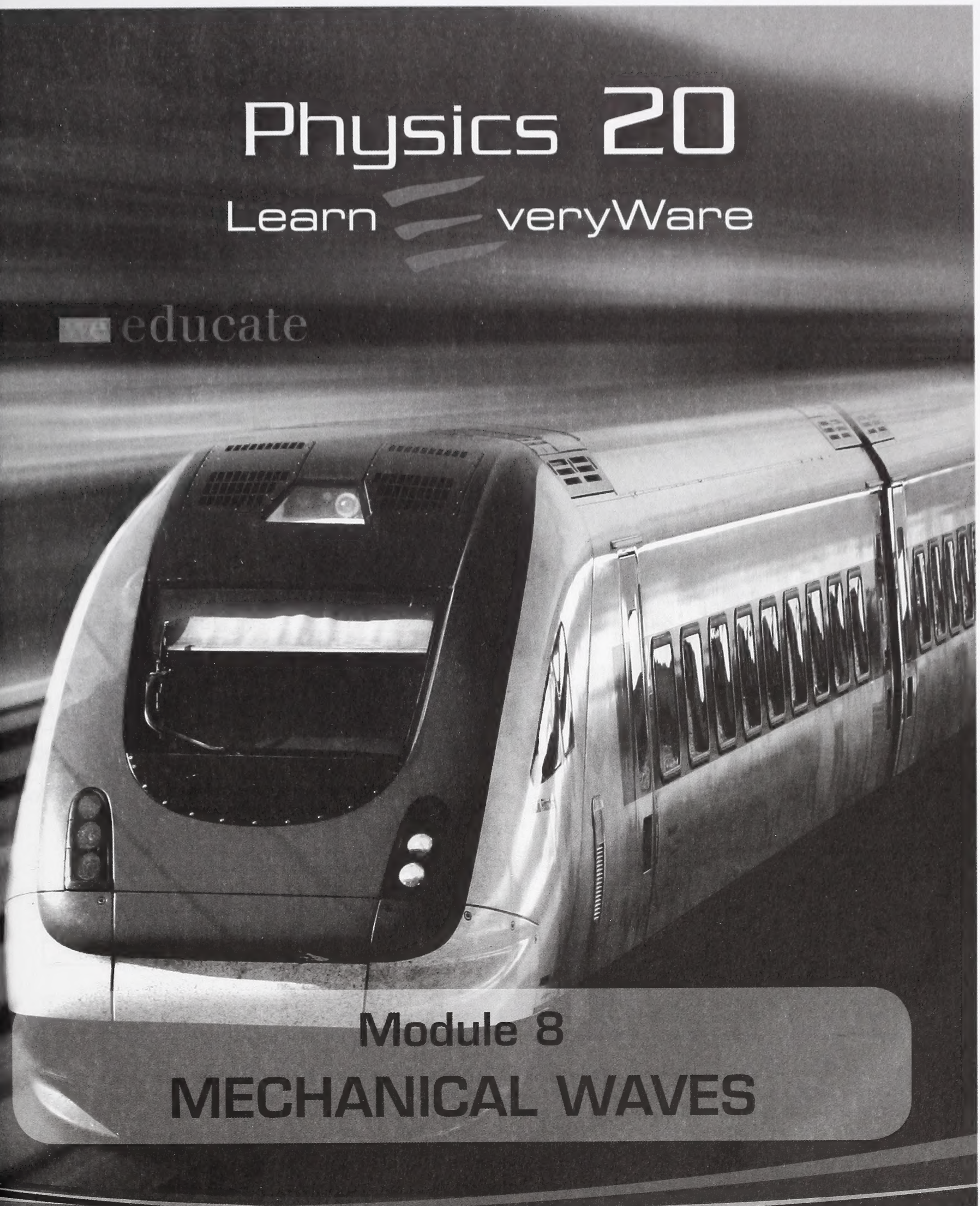

Module 8
MECHANICAL WAVES

Red Deer Catholic Regional Schools

EDMONTON PUBLIC SCHOOLS

Calgary Board of Education

Alberta Education

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- Black Gold Regional Schools
- Calgary Board of Education
- Edmonton School District No. 7
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- Red Deer Catholic Regional Division
- Rocky View School Division No. 41

Physics 20
Module 8: Mechanical Waves
Student Module Booklet
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Students	✓
Teachers	✓
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Home Instructors	
General Public	
Other	

You may find the following Internet sites useful:

- Alberta Education, **http://www.education.gov.ab.ca**
- Learning Resources Centre, **http://www.lrc.education.gov.ab.ca**
- Tools4Teachers, **http://www.tools4teachers.ca**

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Unit D Oscillatory Motion and Mechanical Waves

Module 8—Mechanical Waves

Module Introduction

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In this module you will study properties of mechanical waves. You will learn how mechanical waves transmit energy and how this can help provide solutions to practical problems in your life.

You will be looking at the following essential questions in this module:

- How do mechanical waves transmit energy?
- How is structural design and development of technologies influenced by understanding of wave properties?

Big Picture

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Have you ever been at a concert where you could feel the music? Have you ever been at the movie theatre where you could feel the sound? Just what were you feeling, and what exactly was the physics behind it? Once you've had that experience, you know that sound waves can transmit a lot of energy.

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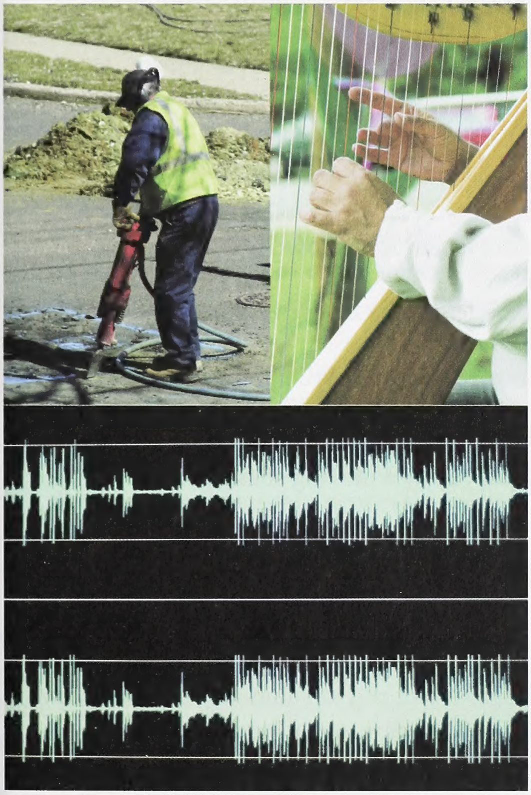
Sound isn't the only wave that can transmit energy. Think about a sunny, tropical beach with the waves rolling in from the ocean. This is another type of wave, and it, too, is carrying energy. If you've ever stood on a beach and let a small wave hit you, you know there is energy in waves. If you have ever seen someone surf in the ocean or have surfed yourself, you will have seen great amounts of energy at work in the rising and falling of water—enough, in fact, to pulverize rock and turn it into sand.

Water waves can also appear as ripples on the water. Think about what happens when you drop a small pebble into water. These waves also transmit energy.

If you look around, you'll see waves and vibrations in lots of different places. Music, like water, provides many good examples when you are talking about waves. The sound waves that make up music can be quite regular, and many instruments make it easy to figure out how the sound is produced.



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bottom: © doctor bass/shutterstock,

It may be hard to accept, but the sounds of a gentle Celtic harp and a jackhammer both get to your ears the same way. In this case, you might want to disagree with Marshall McLuhan's quotation, "The medium is the message," as you look closely at the jackhammer operator and the ear protection needed. This is another indication of the energy that sound can deliver.

An important non-musical sound is an ambulance siren. It's definitely not musical, but the sounds produced by the siren have been chosen just as carefully as the notes chosen by a composer for a song. They need to be heard. They need to pierce through the noise in the environment, yet they cannot be so loud as to damage the hearing of people who are close to the ambulance. You've probably heard another interesting thing about sirens on emergency vehicles. They don't sound the same as they approach and move away from you.

As you work through this module, keep the following questions in mind. They should help you understand mechanical waves.

- What are the properties of mechanical waves?
- What is the difference between a transverse wave and a longitudinal wave?
- How does the universal wave equation relate the frequency, speed, and length of a wave?
- What is the difference between a wave and a ray?
- What happens when a wave encounters a boundary?
- What is Hyguens' Principle? How can it help understand wave reflection?
- How can waves be described using phase and phase angle?
- What is constructive and destructive wave interference?
- What is wave superposition?
- What is a standing wave? How is this related to musical tones?
- How is a standing wave produced in a closed-air column?
- What is the relationship between wavelength and air column length for a closed resonating air column?
- How is a standing wave produced in an open-air column?
- What is the relationship between wavelength and air column length for an open resonating air column?
- What is path length and path difference?
- What is the relationship between path difference and constructive/destructive interference?
- What are nodal and antinodal lines?
- What happens to the wavelength and frequency of sound that is produced by a moving source?
- How does the Doppler equation describe the frequency observed by a moving sound source?

In This Module

Lesson 1—Properties of Mechanical Waves

This lesson introduces mechanical waves. You will learn about transverse and longitudinal waves and how they differ. You will be introduced to properties of waves, such as frequency, speed, and wavelength.

You will explore the following questions:

- What are the properties of mechanical waves?
- What is the difference between a transverse wave and a longitudinal wave?
- How does the universal wave equation relate the frequency, speed, and length of a wave?

Lesson 2—Wave Reflection

You will develop ways to describe waves' motion and use them to describe what happens when waves interact with other objects. You will also learn about Huygens' Principle and how it pertains to wave reflection.

As you work through this lesson, keep these questions in mind:
- What is the difference between a wave and a ray?
- What happens when a wave encounters a boundary?
- What is Huygens' Principle? How can it help to understand wave reflection?

Lesson 3—Wave Phase, Interference, and Standing Waves

In this lesson you will study what happens when waves meet. You will learn about constructive and destructive interference of waves by considering phase angles. You will see how waves' phases lead to standing waves and how this affects the creation of sound in stringed instruments.

You will explore the following questions in this lesson:
- How can waves be described using phase and phase angle?
- What is constructive and destructive wave interference?
- What is wave superposition?
- What is a standing wave? How is this related to musical tones?

Lesson 4—Resonating Air Columns

You will continue your study of standing waves, this time as the standing waves relate to columns of air. You will learn how the length of an air column determines the wavelength of the standing wave. You will also learn how open-air and closed-air columns resonate differently.

You will explore the following questions:
- How is a standing wave produced in a closed-air column?
- What is the relationship between wavelength and air column length for a closed resonating air column?
- How is a standing wave produced in an open-air column?
- What is the relationship between wavelength and air column length for an open resonating air column?

Lesson 5—Two-Point Interference Patterns

You will continue to look at how waves interact. You will learn about the pattern of constructive and destructive interference caused by two wave sources, as well as some new terminology to help you describe these situations. You will also see how interference patterns are related to the distances between the sources and the lengths of the waves.

In this lesson you will explore the following questions:
- What is path length and path difference?
- What is the relationship between path difference and constructive/destructive interference?
- What are nodal and antinodal lines?

Lesson 6—The Doppler Effect

You will consider moving-sound sources in this lesson. You will learn how the sound from a source moving relative to your position appears to be changed. You will also study a mathematical tool, the Doppler equation, which lets you calculate these changes.

You will explore the following questions:

- What happens to the wavelength and frequency of sound that is produced by a moving source?
- How does the Doppler equation describe the frequency observed by a moving sound source?

Module 8 Assessment

The assessment for Module 8 consists of six (6) assignments:

- Module 8: Lesson 1 Assignment
- Module 8: Lesson 2 Assignment
- Module 8: Lesson 3 Assignment
- Module 8: Lesson 4 Assignment
- Module 8: Lesson 5 Assignment
- Module 8: Lesson 6 Assignment

Lesson 1—Properties of Mechanical Waves

Get Focused

When two air masses with different temperature, density, and humidity meet in Earth's atmosphere, rain is produced. In this photo, rain is falling on accumulated puddles of water, producing distinctive circular patterns. Can you tell which raindrops landed more recently than the others? If so, can you figure out exactly where they landed using the patterns observed here?

© Michiel de Boer/shutterstock

The diameter of the circular "waves" is an indication of how recently the raindrop landed on the water. The droplets that produced the larger circles shown in this photo landed before those that produced smaller circles and, if you make a couple of important assumptions, the point of impact for every droplet is at the exact centre of the circular wave. How do you know this is true? Is there a set of universal principles that govern the formation and motion of these circular waves? Do the waves all move outwards at the same speed and, if so, why?

Waves in water can be produced by sources other than rain. Consider dropping a pebble into a lake. You will see a set of ripples (waves) coming from the spot where the pebble hit the surface of the lake. Now, consider dropping a heavy boulder into the lake. In addition to the huge splash of water that would be produced, you would see a set of waves coming from the spot where the boulder was dropped. The source of waves in water is not limited to objects dropping into the water. Waves are also produced when objects come up from under the surface (such as fish) or when a disturbance occurs under the surface—such as a bomb detonating or an earthquake. Can a wave occur in water without any disturbances occurring?

As you work through this lesson, keep the following questions in mind:

- What are the properties of mechanical waves?
- What is the difference between a transverse wave and a longitudinal wave?
- How does the universal wave equation relate the frequency, speed, and length of a wave?

Module 8: Lesson 1 Assignments

Your Lesson 1 Assignment in the Module 8 Assignment Booklet requires you to submit a response to the following:

- Try This—TR 1, TR 2, and TR 3
- Discuss

The other questions in this lesson are not marked by the teacher; however, you should still answer these questions. The Self-Check and Try This questions are placed in this lesson to help you review important information and build key concepts that may be applied in future lessons.

After a discussion with your teacher, you must decide what to do with the questions that are not part of your assignment. For example, you may decide to submit to your teacher the responses to Try This questions that are not marked. You should record the answers to all the questions in this lesson and place those answers in your course folder.

Explore

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This photo is a close-up of a single drop of water landing on a smooth water surface. (The three droplets just above the surface were splashed upwards after impact.) From the point of impact at the centre, waves radiate outwards in all directions, travelling with a constant speed. Here, the water is the **medium** in which the wave energy moves as it disturbs the water surface from its **equilibrium position**. Surrounding the point of impact, there are regions where the water's surface is higher than the equilibrium position. These regions are called **crests**. In other regions, the water level is lower than the equilibrium position. These areas are called **troughs**. The amount of change (up or down) from the equilibrium position is referred to as **amplitude**. All of these descriptors are illustrated below in the side view of a mechanical wave.

medium: the substance that acts as a carrier for a wave

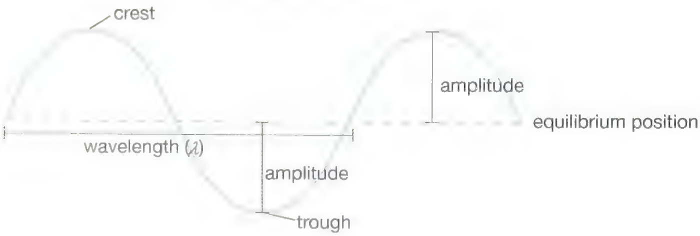
equilibrium position: the position where the medium would normally rest

crest: the highest point in a wave

trough: the lowest point in a wave

amplitude: the measure of the maximum displacement of a wave from the equilibrium position

Mechanical Wave



All periodic waves are defined by having several measurable characteristics. The distance between the centres of consecutive crests and troughs are equal. This is defined as the **wavelength** (λ), which is also illustrated above. Wavelength may also be defined as the distance between any two particles that are moving in the same direction and have the same displacement from the equilibrium position. The symbol for wavelength is the Greek letter *lambda* (λ).

wavelength: the distance between consecutive crests (or troughs)

point source: a source that radiates waves as if it were a point

The mechanical waves discussed in this lesson require three things: some source of disturbance, a medium that can be disturbed, and some physical connection or mechanism through which adjacent portions of the medium can influence each other. To generate a wave, a **point source**, such as a water droplet, earthquake, or nuclear explosion, disturbs the medium. The energy of the disturbance is transferred from one point to another as the particles within the medium vibrate with simple harmonic motion. It is the transfer of energy in this manner that creates a mechanical wave that travels or propagates through the medium.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and watch the video clip called "Hydrogen Bomb Blast," which shows the circular waves produced by the world's first hydrogen bomb blast in the Pacific Ocean.

Read

Read "The Properties of Waves" on pages 394 and 395 of the textbook. Compare the definitions on these pages with those you have already encountered in this lesson.

Module 8: Lesson 1 Assignment

Remember to submit the answer to TR 1 to your teacher as part of your Lesson 1 Assignment.

Try This

TR 1. Define the following terms with the aid of your physics textbook.

a. wave
b. wave front
c. medium
d. incident wave
e. reflected wave
f. wave train

Read

Read "Waves and Rays" on pages 397 to 399 of your textbook.

Self-Check

SC 1. Define a wave ray.

SC 2. When a wave front from a point source reflects off a straight barrier, where does the reflected wave appear to originate?

SC 3.

a. When a straight wave front from a straight wave generator reflects off a straight barrier, where does the reflected wave appear to originate?

b. What is the angle of reflection?

Check your work with the answer in the appendix.

Transverse and Longitudinal Waves

There are two general classifications for waves—**transverse** and **longitudinal**. A toy spring, seen here, is perfect for demonstrating both types of wave motion. If you wiggle one end of the spring up and down, you will produce a transverse wave. Stretching it out and quickly compressing one end of it will generate a moving longitudinal wave. You will use a simulation to compare and contrast both types of waves.

transverse wave: a wave in which the medium moves at right angles to the direction of the wave

longitudinal wave: a wave in which the medium moves parallel to the direction of the wave

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search terms "travelling waves" in the search bar. Choose the item called "Travelling Waves."Open the simulation. Select the "Transverse" option (◉ Transverse) and, click "Play." Carefully compare the motion of the red dot and the motion of the wave itself. You will notice that these motions are not the same. The small red dot represents the *medium* through which the wave is passing. Spend a few minutes experimenting with different settings for both the wavelength and the frequency, and observe the behaviour of both the wave and the medium before attempting the following tasks.

- Using the appropriate "Enter slider value" button ( ), set the wavelength to 90.0 m and the frequency to 0.5 Hz.

- Press "Play."

Self-Check

SC 4.

a. Describe the motion of the red dot (the medium). Does it move horizontally or vertically?

b. Describe the motion of the wave itself. Does it move horizontally or vertically?

c. In what way is the motion of the red dot (medium) distinctly different than the motion of the wave?

Check your work with the answer in the appendix.

On the simulation, select the "Longitudinal" option (◉ Longitudinal), and click "Play." Once again, carefully compare the motion of the red dot and the motion of the wave itself.

Self-Check

SC 5.

a. Describe the motion of the red dot (the medium). Does it move horizontally or vertically?

b. Describe the motion of the wave itself. Does it move horizontally or vertically?

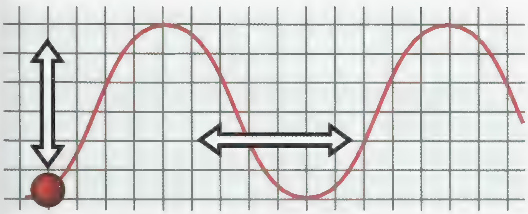
c. How does the distance that the wave travels compare to the distance that the red dot moves over a few seconds of time?

d. In what way is the motion of the red dot (the medium) distinctly different than the motion of the wave?

Check your work with the answer in the appendix.

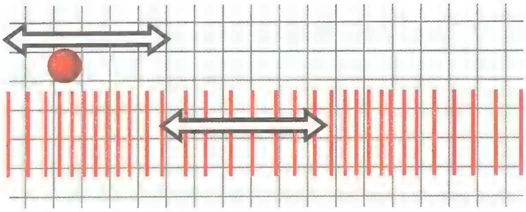
You have just described a key point about wave motion. The motion of the wave and the motion of the medium through which the wave passes are two distinct and different motions. These motions are summarized below.

Transverse Wave Motion



The medium vibrates perpendicular (transverse) to the direction of the wave motion.

Longitudinal Wave Motion



The medium vibrates parallel to the direction of the wave motion.

Comparing the Motion of the Medium with the Motion of the Wave

Does the medium travel as fast as the wave that passes through it? The simulation will now be used to compare the speed of the medium with the speed of the wave.

On the simulation, select the "Transverse" option (◉ Transverse), and set the frequency to 0.5 Hz and the wavelength to 90.0 m. Carefully position the red dot at its lowest point. Do this by clicking "Play," and then immediately click "Pause." Use the "Forward" or "Back" buttons to move the dot to the desired position. Record the time shown at the top of the screen in the table below. Use the "Forward" button to move the dot to its highest point. Record the time again.

Self-Check

SC 6.

a. Complete the following table.

total distance dot travels (1 grid square = 10 m)	
start time (s)	
end time (s)	
time elapsed (s)	
average speed of dot (in m/s)	

b. How fast is the medium moving, and in what direction is it moving?

Check your work with the answer in the appendix.

Next, carefully follow a wave crest. Do this by clicking "Play" and then immediately clicking "Pause." Use the "Back" button to take the time back to zero. Record the position of the first crest by counting the squares. Record the value in the table below. Click "Play" and then a few seconds later, while the crest is still visible, click "Pause."

Self-Check

SC 7.

a. Complete the following table.

initial position of first crest (1 grid square = 10 m)	
final position of first crest (m)	
total distance wave travels (m)	
initial time (s)	0.0 s
time at end (s)	
time elapsed (s)	
average speed of wave (in m/s)	

b. How fast is the wave moving, and in what direction is it moving?

Check your work with the answer in the appendix.

Your observations from this simulation show that the medium and the wave move in distinctly different ways, at different rates, and sometimes in different directions.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and watch the "Transverse vs. Longitudinal Waves" video clip.

On the surface, water waves appear to be transverse waves. A closer look at the medium, however, shows that water waves are, in fact, neither transverse nor longitudinal. Go to your Physics 20 Multimedia DVD, and watch the "Water Waves" video clip to observe the motion of a water medium when a wave passes by.

Read

Read "Transverse and Longitudinal Waves" on pages 401 to 407 of your textbook to find out even more about the topic.

Module 8: Lesson 1 Assignment

Remember to submit the answer to TR 2 to your teacher as part of your Lesson 1 Assignment.

Try This

TR 2. Recall the earlier definitions given in this lesson for the terms listed in the table below. How could each of these terms be defined differently based on the type of wave? A quick diagram may help you explain these.

Term	Transverse Wave	Longitudinal Wave
crest		
trough		
amplitude		
wavelength		

Self-Check

SC 8. Complete question 2 of "Practice Problems" on page 407 of your textbook.

Check your work with the answer in the appendix.

The Universal Wave Equation

All waves obey a fundamental relationship between frequency, wavelength, and the speed of the wave as it passes through the medium. This relationship is known as the **universal wave equation**, which states that the product of the wave frequency and wavelength are always equal to the speed of the wave.

universal wave equation the speed of the wave is equal to the product of the wave frequency and the wavelength

Expressed as an equation, it is

$$v = f\lambda$$

Quantity	Symbol	SI Unit
speed	v	m/s
frequency	f	Hz
wavelength	λ	m

The simulation will be used to verify the universal wave equation. On the simulation, select the "Transverse" (◉ Transverse) wave type.

Self-Check

SC 9. Complete the following table by entering the wavelength and frequency of each wave and recording the necessary data. You can randomly start and pause each of the specified waves to collect the necessary data.

Wavelength (m)	Frequency (Hz)	Total Distance Wave Travels (1 grid square = 250 m)	Time Elapsed (s)	Speed of Wave (m/s)
40	0.25			
90	1.0			
50	1.3			
80	1.6			
75	0.8			

SC 10. Pick two different waves from the preceding table, and use the universal wave equation $v = f\lambda$ to solve for the wave speed. Do the wave speeds determined by the universal wave equation match the observed speeds that were calculated in the table?

Check your work with the answer in the appendix.

Read

Read "Universal Wave Equation" on pages 408 and 409 of your textbook.

Self-Check

SC 11. Complete question 1 of "Practice Problems" on page 409 of your textbook.

Check your work with the answer in the appendix.

Module 8: Lesson 1 Assignment

Remember to submit the answer to TR 3 to your teacher as part of your Lesson 1 Assignment.

Try This

TR 3. Complete question 5 of "8.2 Check and Reflect" on page 410 of your textbook.

Reflect and Connect

When a raindrop strikes the surface of a calm body of water, the energy from the raindrop propagates outwards in all directions in the form of mechanical waves. The speed of these waves can be defined by their wavelength and frequency according to the universal wave equation. Of course, it is not important to

determine the speed of the waves radiating outwards from a raindrop's impact. Larger water waves, however, are of significant interest to those who live near a large body of water. The two photos below show a very small sample of what larger water waves, such as those of tsunami, can do.

left: © A.S. Zain/shutterstock
right: © salamanderman/shutterstock

Consider how the energy of a raindrop and the energy of an earthquake may be related by mechanical waves. Fill a clear glass half full of water, set it on the counter, and bang on the counter once with your fist. What you will see in the glass is similar to what you would see if a drop of water had landed in it. The water medium is disturbed, and the energy of the disturbance propagates outward in the form of a mechanical wave. Hitting the counter harder and harder will produce waves with larger and larger amplitudes. How hard would you have to hit the counter to produce a tsunami like the one that occurred in the Indian Ocean on December 26, 2004?

The water wave directly above the earthquake epicentre was estimated to have an amplitude of about 35 m. For perspective, this is six times higher than the average house. The wave was still 2.6 m high when it reached Mexico, which was 13 000 km away. The inhabitants of the islands and coastal areas of Indonesia and Thailand were simply overwhelmed by the energy of the waves. Use these search terms "NOAA Tsunami Propagation in the Indian Ocean" to find an animation of this tsunami.

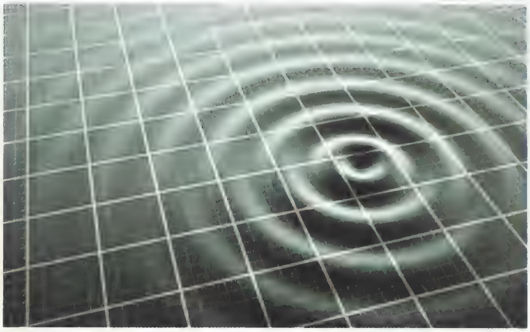
Although the waves look small from space, the energy is very large. The amount of mass that shifted in this event changed the shape of Earth, which has shortened the length of a day by 2.68 microseconds. The total energy released by the earthquake is estimated to be about 3.5 x 1018 J. This is equivalent to about 0.8 billion tons of TNT or the quantity of energy consumed in the United States (by more than 350 million people) in 11 days. It was more than a raindrop, but the energy was dissipated in exactly the same way. To learn more about the tsunami of 2004, search the Internet using the words *2004 Indian Ocean earthquake energy.*

Module 8: Lesson 1 Assignment

Remember to submit the answer to Discuss to your teacher as part of your Lesson 1 Assignment.

Discuss

The Indian Ocean earthquake and subsequent tsunami killed so many people because there was no warning of the impending disaster. It took hours for the first wave to reach many of the shores where widespread death and destruction occurred.



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Research the events that occurred in the Indian Ocean on the morning of December 26, 2004, and post an explanation for the following questions:

- How is it possible to predict the arrival of a tsunami in a coastal area?
- Why is it important to identify the epicentre of the event responsible for producing the tsunami?
- How does a tsunami warning system work?
- How can a tsunami warning system fail?
- Was the Indian Ocean tsunami warning system used effectively in the July 2006 Java earthquake? Why or why not?

You can begin by searching the Internet using the terms *2004 Indian Ocean earthquake signs warnings.*

When you are finished, put your work in your Physics 20 course folder. Your teacher may require you to submit your explanation for feedback or grades.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will deal with waves and transferring energy. To help reinforce your learning from this lesson, complete at least one of the following reflection activities:

- The amplitude of a tsunami is far greater than the amplitude of waves that surfers ride. Create a work of art that depicts the differences between how people are affected by surf and by a tsunami. Your work of art can be a story, poem, song, painting, drawing, or multimedia presentation.

- Think about your experiences with raindrops and ripples in water. Devise an experiment to determine the speed of waves in water.

- The North Shore of the island of Oahu, Hawaii, is said to have some of the best surfing conditions in the world. Determine the average amplitude of waves that occur on the North Shore. Are the waves that surfers ride transverse waves or longitudinal waves?

Store your completed reflection in your Physics 20 course folder.

Module 8: Lesson 1 Assignment

Make sure you have completed all of the questions for the Lesson 1 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 8 assignments have been completed.

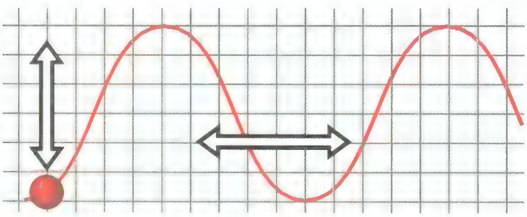
Lesson Summary

As you worked through this lesson, you should have developed partial answers to these questions:

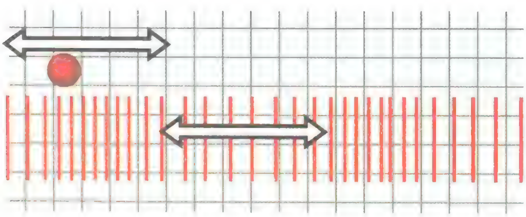
- What are the properties of mechanical waves?
- What is the difference between a transverse wave and a longitudinal wave?
- How does the universal wave equation relate the frequency, speed, and length of a wave?

The mechanical waves discussed in this lesson require three things: some source of disturbance, a medium that can be disturbed, and some physical connection or mechanism through which adjacent portions of the medium can influence each other. To generate a wave, a point source, such as a water droplet, earthquake, or nuclear explosion, disturbs the medium. The energy of the disturbance is transferred from one point to another as the particles within the medium vibrate with simple harmonic motion. It is the transfer of energy in this manner that creates a mechanical wave that travels or propagates through the medium. The wave that transfers the energy is defined by several observable characteristics, such as speed, frequency, wavelength, and amplitude.

The difference between a transverse wave and a longitudinal wave is related to the orientation of the wave motion and the motion of the particle in the medium that carries the wave.



In a transverse wave motion, the medium vibrates parallel to the direction of the wave motion.



In the longitudinal wave motion, the medium vibrates perpendicular (transverse) to the direction of the wave motion.

The universal wave equation states that the product of the wave frequency and wavelength are always equal to the speed of the wave. Expressed as an equation, it is $v = f\lambda$.

Lesson Glossary

amplitude: the measure of the maximum displacement of a wave from the equilibrium position

crest: the highest point in a wave

equilibrium position: the position where the medium would normally rest

longitudinal wave: a wave in which the medium moves in the same direction as the wave

medium: the substance that acts as a carrier for a wave

point source: a source that radiates waves as if it were a point

transverse wave: a wave in which the medium moves at right angles to the direction of the wave

trough: the lowest point in a wave

universal wave equation: the speed of the wave is equal to the product of the wave frequency and the wavelength

wavelength: the distance between consecutive crests (or troughs)

Lesson 2—Wave Reflection

Get Focused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The oil and gas industry of Alberta supplies a significant amount of energy for world markets. In order to help supply the world demand for energy, new sources of oil and gas need to be found as old sources are consumed. Drilling for oil, as seen in the photo here, is costly and dangerous, so oil companies want to have each drilling operation strike productive petroleum deposits. Geologists are employed to explore the subsurface of the ground in an attempt to predict the presence of valuable oil or gas reserves. One of the tools at their disposal is reflection seismology. In this process, a seismic wave is produced on the surface of Earth by TNT or an air gun explosion. The energy of the explosion (similar to a tiny earthquake) travels outward through the ground as seismic waves. Matter deep beneath the surface reflects some of the wave energy. The reflected waves are recorded by a geophone, a portable sensor that converts seismic waves into an electrical signal.

Using the data from the reflected waves, the geologist estimates the properties of the subsurface. In turn, this helps to reduce needless drilling expenses, dangers, and environmental disturbances by focusing exploration on areas that are likely to contain oil and gas deposits of significant value.

The reflected waves that are recorded in seismic geology contain information about the material, or boundaries, that reflected them. How does this reflection occur, and how is it applied in various situations and circumstances to help us understand the physical makeup of the ground beneath our feet?

As you work through this lesson, keep these questions in mind:

- What is the difference between a wave and a ray?
- What happens when a wave encounters a boundary?
- What is Huygens' Principle? How can it help to understand wave reflection?

Module 8: Lesson 2 Assignments

Your Lesson 2 Assignment in the Module 8 Assignment Booklet requires you to submit a response to the following:

- Try This—TR 1, TR 2, and TR 3

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

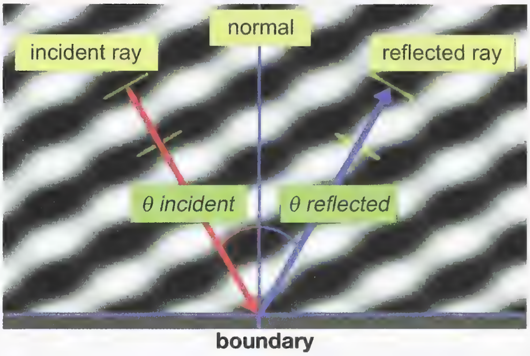
Mechanical waves require a medium to move through. For example, water waves travel through water, typical sound waves travel through air, and seismic waves travel through Earth's surface. You have learned that there are different kinds of mechanical waves—transverse and longitudinal. These waves differ in how the medium is disturbed as the waves move through it.

reflection: a change in direction when a wave strikes and bounces from a surface

Waves also exhibit other distinctive behaviours. Some of these behaviours are common to both particle and wave motion, while others are specific to just wave motion. In this lesson you will investigate what happens when a wave bounces off a surface—**reflection**.

Before you get started, however, it is important to clarify a few terms:

- **normal line:** an imaginary line that is perpendicular to the boundary
- **ray:** a line perpendicular to the wave front depicting the direction the wave is moving
- **incident ray:** the ray that depicts the direction of the wave front that is moving from the point of origin toward the barrier
- **reflected ray:** the ray that depicts the direction of the wave front moving away from the barrier
- **angle of incidence (θ_i):** the angle the incident ray makes with the normal line
- **angle of reflection (θ_r):** the angle the reflected ray makes with the normal line



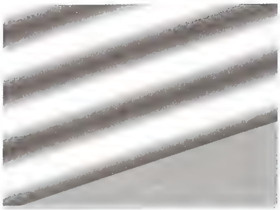
The preceding illustration is an example of a ray diagram. Ray diagrams are often used when studying waves. A ray is a line that depicts the direction that a wave travels. It is always drawn perpendicular to the wave. A ray only shows the direction of a wave, not the wave itself. In the preceding illustration, the incident and reflected rays are drawn. As well, the incident and reflected wave fronts are also sketched in as yellow lines. The wave fronts are perpendicular to the rays. Ray diagrams are a convenient tool to use when studying waves because they represent the direction of motion.

Self-Check

SC 1.

- Draw in the incident ray and the normal line on each of the following diagrams.
- Label the angle of incidence.
- With a protractor, determine the angle of incidence.

The blue line at the bottom of each diagram is the boundary.

a. 

b. 

c. 

Check your work with the answer in the appendix.

We have all heard the echo of our voice or seen the reflection of our face in a puddle. We have all, in some way, experienced the reflection of waves. Simply put, reflection occurs when a wave "bounces" off a surface. But how exactly does a wave bounce off a surface? In this section you will use a simulation to investigate the reflection of mechanical waves.

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search terms "water reflection" in the search bar. Choose the item called "Water Reflection."On the simulation, select "Show Angles" (☑Show Angles) and "Mirror Mode" (☑Mirror Mode) at the top of the window and "Show Calcs" (Show Calcs) at the bottom. Use the simulation to answer the following questions.

Module 8: Lesson 2 Assignment

Remember to submit the answer to TR 1 to your teacher as part of your Lesson 2 Assignment.

Try This

TR 1. Using the values provided in left column of the data table, set the source angle on the simulation. You can set the source angle by dragging the slider below "Source Angle" or clicking the button (#) next to "Source Angle" and filling in the value. Then click "Play," and record the angle of reflection. Although you can simply read the angle of reflection out of the angle data box, it is helpful to actually watch the reflection occur. It may help to turn on "Highlight Reflection" (☑Highlight Reflection) in order to clearly see the reflected waves. Complete the chart.

Source Angle (θ incident)	θ Reflected
10.0°	
20.0°	
30.0°	
40.0°	
50.0°	
60.0°	
70.0°	
80.0°	

Self-Check

SC 2. What is the relationship between the angle of incidence for a wave and its angle of reflection?

Check your work with the answer in the appendix.

You have just discovered the law of reflection, which states that the angle at which a wave approaches a barrier is equal to the angle at which it is reflected. Expressed as an equation, it is

$$\theta_{\text{incident}} = \theta_{\text{reflected}}$$

Your table should show you that the angle of reflection is the same as the angle of incidence. In other words, a wave will bounce off a wall at the same angle that it approached the wall.

Read

In light of what you have just done, review "Waves and Rays" on pages 397 to 399 of your textbook.

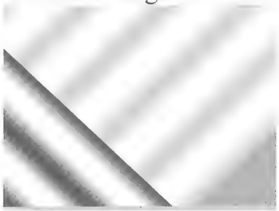
Module 8: Lesson 2 Assignment

Remember to submit the answer to TR 2 to your teacher as part of your Lesson 2 Assignment.

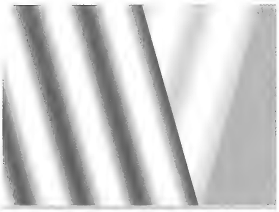
Try This

TR 2. For the following diagrams, sketch in the normal line and the incident and reflected rays. With a protractor, determine the angle of incidence and angle of reflection. Use the "Water Reflection" simulation to check your answer. In each of the images below, the reflected wave is highlighted and the incident wave appears in the background. Be careful—remember that the ray is perpendicular to the wave!

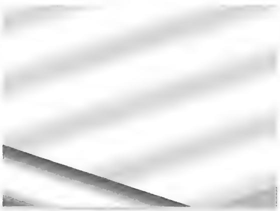
a.



b.



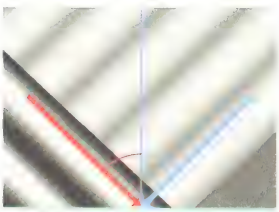
c.



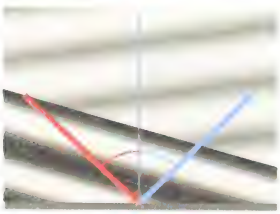
Self-Check

SC 3. Identify which of the following diagrams are the ray diagrams drawn correctly. A correct ray diagram has rays that are perpendicular to the wave fronts. For diagrams that are incorrect, draw in the corrected rays.

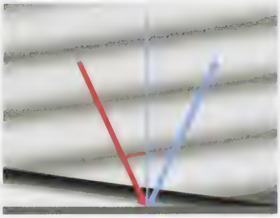
a.



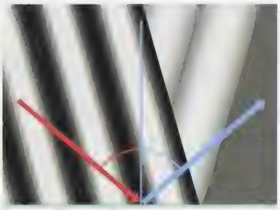
b.



c.



d.



Check your work with the answer in the appendix.

Module 8: Lesson 2 Assignment

Remember to submit the answer to TR 3 to your teacher as part of your Lesson 2 Assignment.

Try This

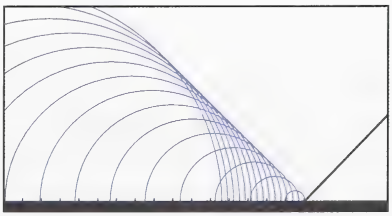
TR 3. Draw a ray diagram to show the reflection of a wave that is incident to a surface at an angle of 20.0°. Use the "Water Reflection" simulation to verify your answer.

Self-Check

SC 4. Draw a ray diagram to show the reflection of a wave that is incident to a surface at an angle of 0°.

Check your work with the answer in the appendix.

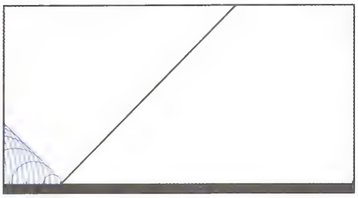
Huygens' Principle and Reflection

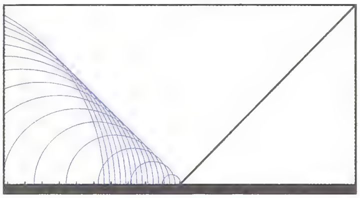


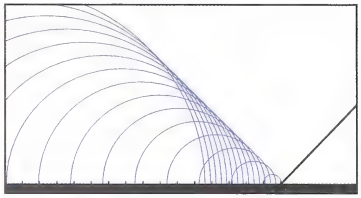
Christian Huygens was a Dutch physicist who lived during the seventeenth century. Huygens described an elegant and conceptual model of how waves travel. He stated that any wave front can be thought of as a series of points. Each point acts as a source of tiny secondary waves, called **wavelets**, which propagate outward in concentric circles at the same speed as the wave itself. The line tangent to the wavelets represents the wave front. This idea, called Huygens' Principle, can be used to explain reflection.

wavelet: a secondary wave

Imagine a wave front that is travelling towards a surface. This wave front can be viewed as a series of point sources, each emitting wavelets. As each point source reaches the surface, it emits wavelets. The wavelets are emitted in sequence over a given time interval—the first wavelets will have propagated the farthest, followed by the wavelets from the second point source, followed by the wavelets from the third point source, and so on. If the line tangent to the wavelets is drawn, you can see that the reflected wave front leaves the surface at the same angle as the incident wave front approaches it. The series of diagrams below shows a wave front reflecting from a surface over time.







Watch and Listen

Go to your Physics 20 Multimedia DVD to see how wave reflection occurs according to Huygens' Principle. Choose the item called "Huygens' Principle." Notice how the wave fronts from several point sources add up to a straight wave front. You will learn more about addition of waves in the next lesson.

Reflect and Connect

In seismic exploration, a small charge of TNT is ignited, causing seismic waves to propagate downward into Earth. Earth itself is the medium in which the seismic waves travel. Each layer of Earth, composed of various materials, will tend to change the speed of the seismic waves. Therefore, when a seismic wave encounters a boundary between two different media, some of the wave energy is reflected according to the law of reflection, while some of the wave energy is transmitted.

Photo courtesy Captain Budd Chirstman, NOAA Corps

Measuring the time it takes for the reflected waves to return to the surface (where they are sensed by the geophone) indirectly indicates the depth of a boundary. This indicates a change in the type of material making up the subsurface. Using the direction of the wave, the location of the boundary can be identified. Understanding the location of the boundaries and the relative impedance (resistance to the waves) of the materials making up these boundaries allows a geologist to estimate the properties of the material causing the reflection. The law of reflection allows the geologist to apply similar analyses in a variety of locations and circumstances, helping us understand what lies deep in the ground beneath our feet. Can similar techniques be applied to explore the sea floor using sound waves instead of seismic waves? Check it out on the Internet by using the search terms *reflection seismology deep water marine*.

Discuss

The large satellite dish on the left can be used for astronomy and large-scale communications. The small satellite dish on the right is typical of most home satellite TV and/or Internet services. Notice the shapes of these dishes are similar. What does this shape have to do with the law of reflection? In this lesson you looked at how waves reflect off a straight surface. But, what happens when a wave approaches a curved surface? The following diagram shows waves approaching a curved surface. Several incident rays are drawn. Draw in the reflected rays. **Hint:** Draw in the normal for each ray that is hitting the surface. Then apply the law of reflection in order to draw the reflected rays. The bottom one has been done as an example.

left: © Manfred Steinbach/shutterstock
right: © Gyula Matics/shutterstock

In the discussion forum, explain why all satellite dishes have a similar shape and where you would expect all the reflected rays to intersect. What would you position at the point where all the reflected rays intersect? Why?

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will deal with waves and transferring energy. To help reinforce your learning from this lesson, complete at least one of the following reflection activities:

- Think about your experiences with sound. Have you experienced reflection of sound waves in an interesting manner? Create an amusing story relating to reflected sounds (perhaps an echo).

- When the Jubilee Auditoriums in Edmonton and Calgary were refurbished recently, there was great consideration given to the acoustics in the halls. Does the reflection of sound waves make the listening experience better or worse? Do some research to answer this question, and find out how you can increase or decrease reflection in a music hall to create a better listening experience for the audience.

Store your completed reflection in your Physics 20 course folder.

Module 8: Lesson 2 Assignment

Make sure you have completed all of the questions for the Lesson 2 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 8 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have developed partial answers to these questions:

- What is the difference between a wave and a ray?
- What happens when a wave encounters a boundary?
- What is Huygens' Principle? How can it help to understand wave reflection?

A ray is a line that depicts the direction that a wave travels. It is always drawn perpendicular to the wave, showing the wave's direction of travel not the wave itself. Ray diagrams are a convenient tool to use when studying waves because they represent the direction of motion and can be used to predict the precise angle of reflection from a smooth surface.

When a wave encounters a boundary, the law of reflection is applied such that the angle at which a wave approaches a barrier is equal to the angle at which it is reflected. Expressed as an equation, it is $\theta_{\text{incident}} = \theta_{\text{reflected}}$.

Any wave front can be thought of as a series of points. Each point acts as a source of tiny secondary waves, called wavelets, which propagate outward in concentric circles at the same speed as the wave itself. The line tangent to the wavelets represents the wave front. This idea, called Huygens' Principle, can be used to explain reflection.

Lesson Glossary

angle of incidence (θ_i): the angle that an incident ray makes with the normal line

angle of reflection (θ_r): the angle that a reflected ray makes with the normal line

incident ray: the ray that depicts the direction of the wave front that is moving from the point of origin toward the barrier

normal line: an imaginary line that is perpendicular to the boundary

ray: a line perpendicular to the wave front depicting the direction the wave is moving

reflected ray: a ray that depicts the direction of the wave front moving away from the barrier

reflection: a change in direction when a wave strikes and bounces from a surface

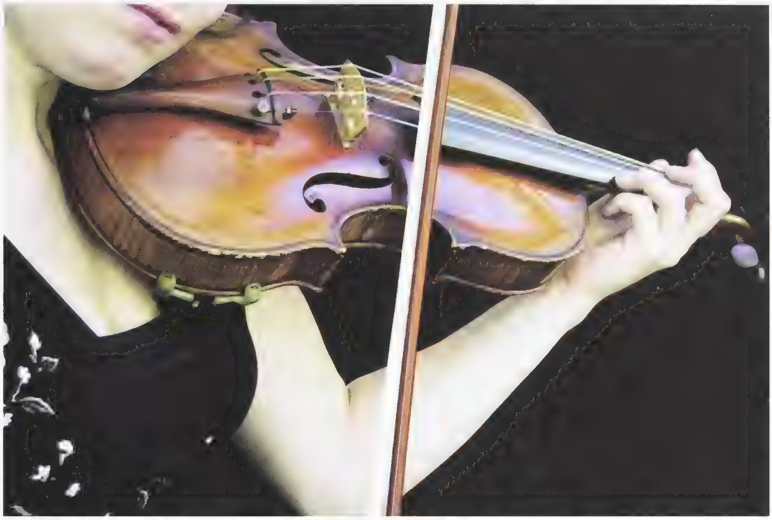
wavelet: a secondary wave

Lesson 3—Wave Phase, Interference, and Standing Waves

Get Focused

In Lesson 2 you learned that when a wave encounters a boundary, it is reflected in a very predictable way. With the right equipment, this fact helps geologists understand the physical makeup of the boundaries below Earth's surface. Can the same principles of wave reflection be applied to help you understand the notes produced by a stringed musical instrument, such as a violin or guitar?

When a musician disturbs the fine strings of a violin, the strings vibrate and produce a wave that propagates along the string.



© Denis Pepin/shutterstock

The wave quickly encounters a boundary, either the musician's fingers or the physical end of the string. At this point, the wave is reflected back along the string, even though the strings are still being disturbed by the musician. This means the reflected wave will encounter more waves travelling in the opposite direction. What happens to the string when two waves encounter one another while travelling in opposite directions? Will they interfere with one another to produce a new wave? Will they pass through one another undisturbed? How is this interaction and resulting pattern sensed by your ears? How exactly is wave reflection and interference related to music?

As you work through this lesson, keep the following questions in mind:

- How can waves be described using phase and phase angle?
- What is constructive and destructive wave interference?
- What is wave superposition?
- What is a standing wave? How is this related to musical tones?

Module 8: Lesson 3 Assignments

Your Lesson 3 Assignment in the Module 8 Assignment Booklet requires you to submit a response to the following:

- Try This—TR 1, TR 2, TR 3, TR 4, TR 5, TR 6, and TR 7
- Discuss

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

The following image shows a transverse wave similar to one that would be produced in the string of a musical instrument when it is disturbed.

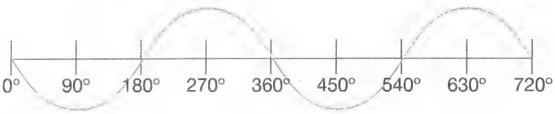


Figure 1

> **phase shift:** for two sine waves, the change in angle needed to change the first sine wave into the second

A transverse wave is a sine curve, so called because it is like the graph of the sine function in trigonometry. The angle on the horizontal axis is referred to as the phase angle, and it describes the relative position of the waveform along the horizontal axis. In other words, the wave's movement can be measured by a change in phase angle. For example, if the waveform in Figure 1 undergoes a negative 90° **phase shift**, it moves 90° to the right along the axis, as illustrated in Figure 2.

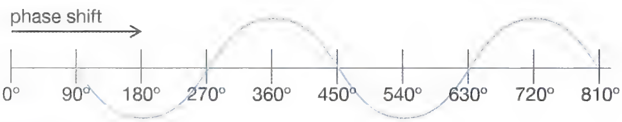
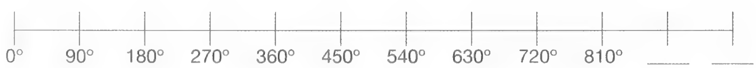


Figure 2

Self-Check

SC 1. Draw a negative 180° phase shift for the same transverse waveform shown in Figure 1, and fill in the last two missing angles on the axis.



Check your work with the answer in the appendix.

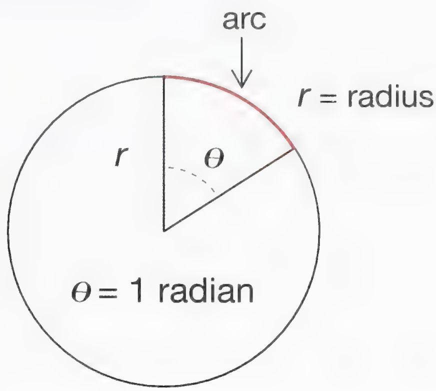
Using Radians to Measure Angles and Phase

You are probably familiar with using degrees to measure angles. Another measure that is frequently used in physics and mathematics is **radian** measure. You encountered it in Module 7: Lesson 1. Radians are just another way to measure angles. Conceptually, degrees or radians can be used to measure angles just like Canadian (Imperial) gallons or American gallons can be used to measure volume. An angle of 1 radian (rad)

lies between two radii of a circle that cut off an arc on the circumference between them whose length is equal to the radius. Therefore,

1 rad = approximately 57.3°

This is how a radian is defined: If the arc on the circumference of a circle is equal in length to the radius of the circle, the angle between the arms of the arc is one radian. This is shown below. The length of the arc marked in red is equal to the circle's radius. Angle (θ) is one radian.



Since a circle has a circumference defined by $C = 2\pi r$, rotating through an entire circle is the same as rotating through 2π radians. This gives the "conversion" factor between degree measure and radian measure:

2π radians = one complete rotation or 360°
π radians = 180°

Module 8: Lesson 3 Assignment

Remember to submit the answer to TR 1 to your teacher as part of your Lesson 3 Assignment.

Try This

TR 1. Complete the following graph using the radians-degrees conversion factor.

degrees	0°	90°	180°	____	360°	450°	____	630°	____	810°
radians	0π	0.5π	____	1.5π	____	____	3.0π	____	4.0π	____

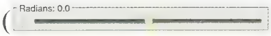
Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search terms "wave phase" in the search bar. Choose the item called "Wave Phase and Interference." This simulation will be used to explore the concept of wave phase and how this relates to position.

When using the simulation, radian measure is used. When you enter a value for the phase (φ) of a wave, radians will be used to calculate the horizontal position of the wave.

Module 8: Lesson 3 Assignment

Remember to submit the answer to TR 2 to your teacher as part of your Lesson 3 Assignment.

Try This

TR 2. Use the phase slider (

) on the simulation to investigate how wave phase affects the position of a wave (the blue wave) as it is drawn along the horizontal axis of a graph.

a. A negative phase or decrease in the phase shifts the wave to the ______________ along the horizontal axis.

b. A positive phase or increase in the phase shifts the wave to the ______________ along the horizontal axis.

c. Two waves will overlap exactly (i.e., match up) only when the phase of one of the waves is exactly 2π radians greater than the phase of the other wave. Is this statement **true** or **false**? Explain your answer.

Constructive and Destructive Wave Interference

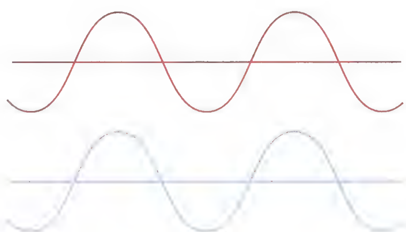
Read

What is constructive interference or destructive interference of waves? Read "Superposition of Pulses and Interference" on pages 411 to 413 of your textbook to help understand what the following assignment questions are about.

Consider what happens when two waves of identical wavelength combine. There are three possible cases:

- in phase (crest meets crest)
- out of phase (crest meets trough)
- intermediate phase (crest meets neither crest nor trough)

Case 1: In Phase



In this case, the crests (and troughs) line up, as illustrated. The waves will combine constructively and produce the largest possible combined amplitude.

Use the "Wave Phase and Interference" simulation to explore this. Choose 100 m as the wavelength, and make sure that the amplitudes for both waves are the same. Use the "down" arrow to move the waves closer to each other. Slide the phase scrollbar back and forth, and note when the waves match up crest to crest or trough for trough. These are the conditions for **constructive wave interference**. Such waves are said to be in phase.

constructive wave interference: overlapping of waves so the crests match with crests and troughs match with troughs

Module 8: Lesson 3 Assignment

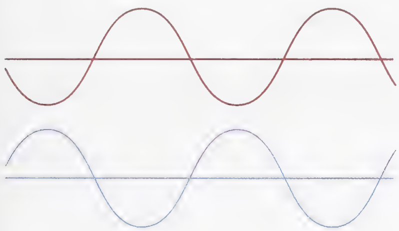
Remember to submit the answer to TR 3 to your teacher as part of your Lesson 3 Assignment.

Try This

TR 3. The green waveform at the bottom of the simulation shows the combined waveform. Sketch the waveform when the two waves are in phase or complete constructive interference. Compare the amplitude of the combined waveform with the amplitude of the individual waveforms. Which wave has the larger amplitude?

Case 2: Out of Phase

In this case, the crest of one wave lines up with the trough of another, as illustrated.



destructive wave interference: overlapping of waves so crests match with troughs

The waves will undergo **complete destructive wave interference**.

Use the "Wave Phase and Interference" simulation to explore this. Again, adjust the phase by moving the phase scrollbar, and observe when complete destructive interference occurs. When this occurs, the waves are said to be "completely out of phase."

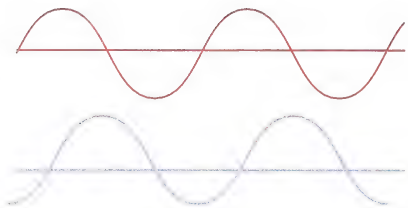
Module 8: Lesson 3 Assignment

Remember to submit the answer to TR 4 to your teacher as part of your Lesson 3 Assignment.

Try This

TR 4. The green waveform at the bottom of the simulation shows the combined waveform. Sketch the waveform when the two waves are completely out of phase or complete destructive interference. Compare the amplitude of the combined waveform with the amplitude of the individual waveforms. Which wave has the smaller amplitude?

Case 3: Intermediate Phase



In this case, neither crests nor troughs line up, as illustrated.

The waves still add, but they no longer cancel completely or add up to the maximum possible amplitude.

Use the "Wave Phase and Interference" simulation to explore this. Again, adjust the phase by moving the phase scrollbar, and observe when this occurs.

Module 8: Lesson 3 Assignment

Remember to submit the answer to TR 5 to your teacher as part of your Lesson 3 Assignment.

Try This

TR 5. The green waveform at the bottom of the simulation shows the combined waveform. Sketch an example of the combined waveform when the two waves undergo intermediate interference, and compare the amplitude of the combined waveform with the amplitude of the individual waveforms.

Self-Check

SC 2. In the simulation, use the phase scrollbar to determine how big a phase shift (in radians) must be introduced between waves so that complete destructive interference occurs. What two other conditions must also be met in achieving complete destructive interference?

SC 3. Adjust the amplitude of wave 1 to be 10 units and wave 2 to be 20 units. Choose a wavelength of 100 m. (This makes the waves large enough to be easily seen.)

a. What is the maximum possible amplitude of the combined wave when wave 1 and wave 2 constructively interfere?

b. What is the minimum possible amplitude of the combined wave when wave 1 and wave 2 destructively interfere?

Check your work with the answer in the appendix.

Module 8: Lesson 3 Assignment

Remember to submit the answers to TR 6 and TR 7 to your teacher as part of your Lesson 3 Assignment.

TR 6. Adjust the amplitude of wave 1 to be 5 units and wave 2 to be 12 units. Choose a wavelength of 100 m. (This makes the waves large enough to be easily seen.)

a. What is the maximum possible amplitude of the combined wave when wave 1 and wave 2 constructively interfere?

b. What is the minimum possible amplitude of the combined wave when wave 1 and wave 2 destructively interfere?

TR 7. Two waves are originally in phase. If one of the waves is shifted by 4π radians, the waves will now be completely out of phase. Is this statement **true** or **false**? Explain your answer.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and use the "Superposition Principle of Waves" simulation to visualize the principle of superposition when two identical waves meet. Stop the action by right-clicking (press the button on the right side of your mouse), and change the frequency to 4.0 Hz for both waves. Press "Enter" and right-click again to start the action. You can stop or start it at any time by right-clicking.

Standing Waves and Musical Tones

As you observed in the simulation, when two identical waves approach one another, they begin to interfere. As the crest of one wave meets the trough of the other, destructive interference causes the medium to lay flat, as illustrated by the small red line, just as the two waves start to overlap. As the overlap continues, constructive interference also occurs when crests and troughs begin to meet one another. This produces a larger amplitude wave, as seen in the third line of the image below.

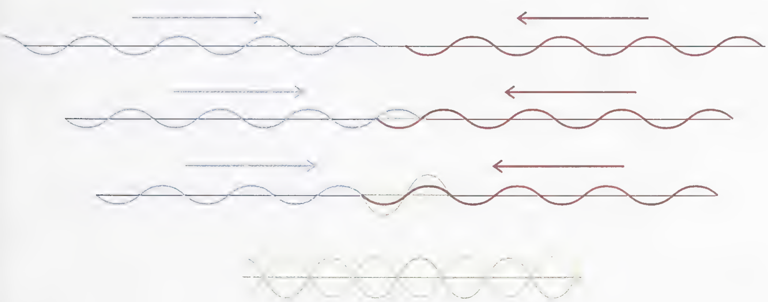


Figure 3

The last part of the image shows a **standing wave**. This is the result when the two waveforms are completely overlapped. Since the waves continue to move, the combined waveform flips up and down. The pattern at work in the preceding Watch and Listen activity is shown in Figure 4. You will notice that in both the simulation and in Figure 3, there are points along the standing wave that do not move (hence the term *standing*) and points that move up and down at maximum amplitude. Points that do not move are called **nodes**, and points that move at maximum amplitude are called **antinodes**.

standing wave: a wave that appears not to be travelling (stays in a constant position)

antinode: a place on a standing wave with maximal amplitude

node: a place on a standing wave with minimal amplitude

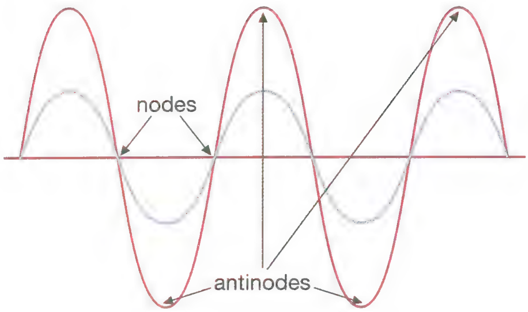
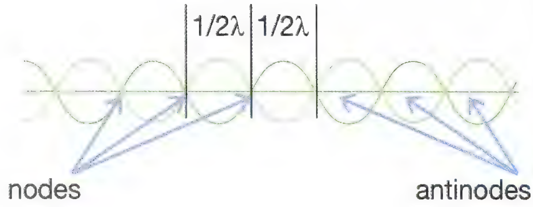


Figure 4



As shown in the previous diagrams, the nodes are separated by one-half wavelength (½ λ) intervals, as are the antinodes.

resonant frequency: the frequency at which an object naturally vibrates

In stringed instruments, such as a violin or guitar, there must be a node at each end of the string where it is attached to the instrument. This could be the physical end of the string or the point where the musician's finger presses the string so that the string is in contact with the neck of the instrument. In each string on the instrument, there will be an integral number of antinodes between the nodes on each end of the standing wave patterns that are produced when the string is disturbed. In other words, the standing wave in the string will prefer to oscillate with a specific number of antinodes, producing a **resonant frequency** (recall the earlier definition of *resonance*). On musical instruments, the standing wave frequency is unique to the string and instrument and is observed by the human ear as a tone or note.

Read

Read "Standing Waves and Resonance" on pages 416 to 418 of your textbook.

Self-Check

SC 4.

a. What is the difference between a node and an antinode?
b. How far apart will they occur?

Check your work with the answer in the appendix.

Reflect and Connect

In your house or classroom, find a rope, a string, or even a long electrical extension cord. The rope should be more than 3 m long. Tie one end of the rope to a fixed position, such as a doorknob or railing. Hold the other end in your hand, and pull the rope tightly straight outwards from the fixed end. If you move the end in your hand up and down once, you will see the wave travel down the length of the rope until it reaches the fixed

end, at which point it will be reflected. If you move your hand up and down continually at a constant frequency, you will start to observe interference as new waves make contact with reflected waves. The pattern of constructive and destructive interference may look completely random, but if you slowly increase the frequency at which your hand moves up and down, a standing wave pattern will appear. Once you see the standing wave pattern, you can maintain it as long as you keep the frequency constant.

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By looking at the rope, you should be able to identify the nodes (spots that do not move) and the antinodes (spots that flip up and down at maximum amplitude). You are seeing a standing wave in action.

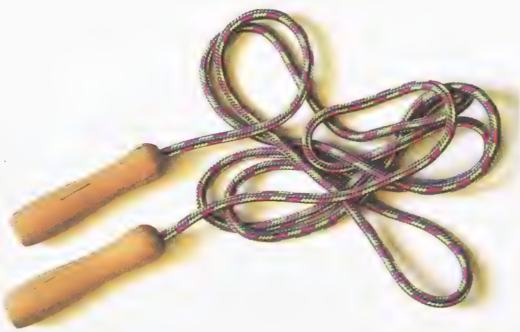
Now, go back and look at the standing wave pattern illustrations above. Does your wave look the same? Probably not, since a standing wave diagram is static, meaning that it doesn't move. When you set it up on a rope, you can see how the pattern flips back and forth. This is a more realistic observation of a standing wave pattern. A violin string behaves the same way. However, the standing wave pattern would oscillate at a much, much higher frequency—so high, in fact, that your ears can hear it! Each pure tone produced by the violin is based on one specific standing wave pattern—its resonant frequency. This can also happen on a much larger scale, as you observed in Module 7: Lesson 3 with the Tacoma Narrows suspension bridge.

Module 8: Lesson 3 Assignment

Remember to submit the answer to Discuss to your teacher as part of your Lesson 3 Assignment.

Discuss

At some point in your life, you have probably had an opportunity to skip rope with a couple of friends. If you have one rope, you can skip by yourself or you can include two friends, each holding one end of the rope with you in the middle. Your friends are the nodes, and you are the antinode. Is it possible to skip rope with three other friends, with two of you in the middle jumping at different times?



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In the discussion forum, explain how two jumpers can be in the middle in such a way that only one person has to jump at a time. In your explanation, refer to the terms *node*, *antinode*, and *frequency*.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module will deal with waves and transferring energy. To help you reinforce your learning from this lesson, complete at least one of the following reflection activities:

- Think about a room with a single violinist playing. Think about the reflections from the walls and ceiling. You and a friend are both in the room. Explain to your friend why you might have heard some of the notes much louder than your friend heard them.

- What shape of room would make listening to a symphony orchestra most enjoyable? Do some research to find the shapes and sizes of concert halls where major orchestras might perform.

Store your completed reflection in your Physics 20 course folder.

Module 8: Lesson 3 Assignment

Make sure you have completed all of the questions for the Lesson 3 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 8 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have developed answers to the following questions:

- How can waves be described using phase and phase angle?
- What is constructive and destructive wave interference?
- What is wave superposition?
- What is a standing wave? How is this related to musical tones?

Since a transverse wave is a sine curve, a phase angle can be used to describe the relative position of the waveform along a horizontal axis on which it is moving. In other words, wave movement can be measured by a change in phase angle.

Constructive interference occurs when two waves or pulses are in phase (crest to crest or trough to trough), creating a waveform with a greater amplitude. Destructive interference occurs when two waves or pulses are out of phase (crest to trough), creating a waveform with smaller amplitude—zero in the case of complete destructive interference.

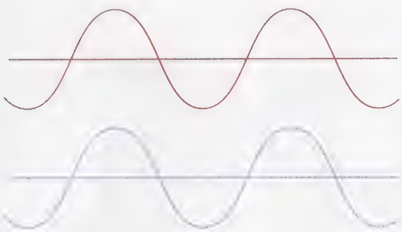
The principle of superposition states that the displacement of the combined waveform or pulse at each point of interference is equal to the sum of the displacements of the individual waveforms or pulses.

A standing wave is a condition in a medium where a wave seems to oscillate around stationary points called nodes. This occurs at specific frequencies particular to the medium and in musical instruments that produce specific tones you can hear.

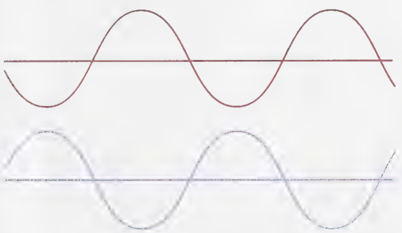
Lesson Glossary

antinode: a place on a standing wave with maximal amplitude

constructive wave interference: overlapping of waves so the crests match with crests and troughs match with troughs



destructive wave interference: overlapping of waves so crests match with troughs



node: a place on a standing wave with minimal amplitude

phase shift: for two sine waves, the change in angle needed to change the first sine wave into the second

resonant frequency: the frequency at which an object naturally vibrates

standing wave: a wave that appears not to be travelling (stays in a constant position)

Lesson 4—Resonating Air Columns

Get Focused

What would happen if you were to blow across the top of one of the bottles in this photo? If you did it right, a sound would be produced. Find an empty bottle, and try it now.

What do you think would happen if you poured some water into your bottle? Would the tone change? Yes, it would; but how it changes would depend on how much water you put into the bottle. The tone produced by each bottle depends on the length of the air column in the bottle itself. When you add water, you effectively change the length of the air column in the bottle. From your studies in Module 8: Lesson 2, this implies that the sound wave produced by the airflow at the top of the bottle must enter the bottle, reflect off the bottom, and return to the top. This means that wave interference must occur inside the bottle.

As you observed from the rope exercise from Lesson 3, a standing wave is always produced at a resonant frequency specific to the length of the medium that the wave travels. In this case, the medium is the air inside each bottle.

There are many examples of air columns that carry sound waves. Pipe organs and wind instruments, such as the flute and trumpet, are all resonating air columns. How is mechanical resonance applied to produce desired tones in such instruments? How do the principles of superposition, interference, and reflection apply to air columns that are closed on one end, such as a bottle, or ones that are open at both ends, such as an organ pipe?

As you work through this lesson, keep the following questions in mind:

- How is a standing wave produced in a closed-air column?
- What is the relationship between wavelength and air column length for a closed resonating air column?
- How is a standing wave produced in an open-air column?
- What is the relationship between wavelength and air column length for an open resonating air column?

Module 8: Lesson 4 Assignments

Your Lesson 4 Assignment in the Module 8 Assignment Booklet requires you to submit a response to the following:

- Try This—TR 1, TR 2, TR 3, and TR 4
- Discuss

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

The organ pipes seen here sit on top of a windchest. The windchest is connected by wind trunks (large tubes) to a reservoir of lightly compressed air. When the musician presses a key on the keyboard, valves open and air escapes from the windchest. This moving air acts on specific pipes. The airflow and the design of the pipe cause the pipe and the air in the pipe to vibrate. A standing wave that is specific to the dimensions of that pipe is produced.

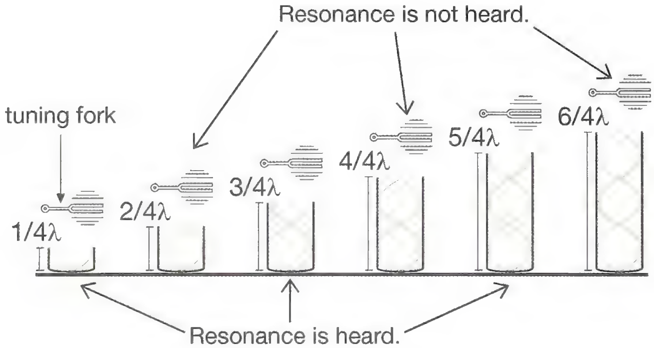
Each pipe encloses an air column of specific length that is capable of holding a standing wave pattern as long as the windchest supplies moving air. There are two types of air column—a closed one, where one end of the air column is sealed so that waves are reflected, and an open one, where both ends of the air column are open.

If you are interested in learning more about the workings of pipe organs, search on the web for “Pipe Organ Education Project.”

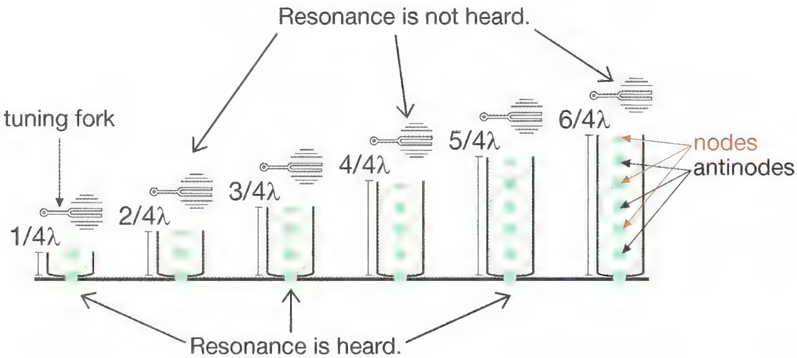
Closed-air Column Resonance

Although sound waves are longitudinal waves, they will be represented here as transverse waves simply for the purpose of visualizing them inside an air column.

Consider six closed-air columns with different lengths, as shown below. A tuning fork is struck and then held over the opening of each air column. Three of the air columns resonate, which is observed as an amplification of the sound produced by the tuning fork. Three do not resonate—only the sound of the tuning fork can be heard at the top of each of these air columns. Why the difference?



When the sound wave enters the column at the opening, it travels downward, reflecting from the bottom surface. The reflected wave encounters more incoming waves, and a standing wave pattern is produced (shown in green). Identifying the nodes and antinodes in the pattern indicates that a closed-air column will resonate loudly when an antinode (point of complete constructive interference) is at the opening of the air column. This occurs when the air column length is one-quarter that of the wavelength and then again every one-half wavelength $\left(\text{e.g., } \frac{1}{4}\lambda, \frac{3}{4}\lambda, \frac{5}{4}\lambda\right)$.



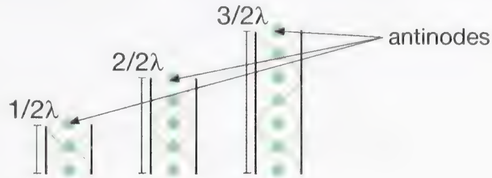
If the length of the air column is adjusted so that a node (point of complete destructive interference) is at the opening, no sound will be heard coming from the air column. This occurs when the air column length is a multiple of one-half the wavelength $\left(\text{e.g., } \frac{2}{4}\lambda, \frac{4}{4}\lambda, \frac{6}{4}\lambda\right)$.

Closed-air column resonance is heard when an antinode exists at the opening of the air column. This occurs when the air column is $\frac{1}{4}\lambda, \frac{3}{4}\lambda, \frac{5}{4}\lambda,$ and so on. Expressed as an equation, it is $L = \frac{1}{4}\lambda, \frac{3}{4}\lambda, \frac{5}{4}\lambda,$ and so on.

Quantity	Symbol	SI Unit
length	L	m
wavelength	λ	m

Open-air Column Resonance

If the air column is open on both ends, resonance will only be heard when the air column is a multiple of ½ of the standing wavelength, as shown below.



Open-air column resonance is heard when an antinode exists at both openings of the air column. This occurs when the air column is $\frac{1}{2}\lambda, \frac{2}{2}\lambda, \frac{3}{2}\lambda,$ and so on. Expressed as an equation, it is $L = \frac{1}{2}\lambda, \frac{2}{2}\lambda, \frac{3}{2}\lambda,$ and so on.

Quantity	Symbol	SI Unit
length	L	m
wavelength	λ	m

Read

How is this equation used in calculations? Read “Resonating Air Columns” on pages 418 to 420 of your physics textbook.

Self-Check

SC 1. Complete question 2 of “Practice Problems” on page 420 of your textbook.

Check your work with the answer in the appendix.

Module 8: Lesson 4 Assignment

Remember to submit the answers to TR 1, TR 2, and TR 3 to your teacher as part of your Lesson 4 Assignment.

Try This

TR 1. A tuning fork of frequency 440 Hz is held above an air column that is gradually increased in length. What is the length of the air column that will produce the second resonance position when the speed of sound is 336 m/s?

TR 2. What is the speed of sound where a tuning fork of frequency 262 Hz produces the third resonance position above an air column that is 1.59 m in length?

TR 3. The speed of sound is 340 m/s where a tuning fork produces the second resonance position above an air column that is 49.8 cm in length. What is the frequency of the tuning fork?

Read

Musical instruments sound much richer than tuning forks. Read "Music and Resonance" on pages 422 to 424 of your physics textbook.

Self-Check

SC 2. The speed of sound varies with changes in air pressure and temperature. To get the correct fundamental frequency, musical instruments must be tuned. Explain how the adjustment to tune stringed instruments is different than the adjustment to tune wind instruments.

Check your work with the answer in the appendix.

Watch and Listen

Go to your Physics 20 Multimedia DVD, and use the "Standing Longitudinal Waves" simulation to explore both open- and closed-air column resonance.

Self-Check

SC 3. To check your understanding of superposition and interference for waves in air columns, use the Standing Longitudinal Waves applet to answer the following questions:

a. Choose "both sides open." Then select "Higher" vibrational mode twice to get the second overtone. For the second overtone when a tube that has both sides open, how many wavelengths is the length of the tube?

b. Choose "one side open." Then select "Higher" vibrational mode until you get the third overtone. For the third overtone when a tube that has one side open, how many wavelengths is the length of the tube?

Check your work with the answer in the appendix.

Module 8: Lesson 4 Assignment

Remember to submit the answer to TR 4 to your teacher as part of your Lesson 4 Assignment.

Try This

TR 4. Use the Standing Longitudinal Waves applet to answer the following questions:

a. For the third overtone when a tube that has both sides open, how many wavelengths is the length of the tube?

b. For the first overtone when a tube that has one side open, how many wavelengths is the length of the tube?

Reflect and Connect

Air column resonance, whether open or closed, is heard as an amplification of the tone that enters the air column. The amplification is based on constructive interference that occurs at the opening (or openings) of the air column. Each organ pipe is cut to a specific length so that the standing wave inside of it will exhibit constructive interference at the openings. In order to predict the length of pipe that will resonate, an organ designer has to know the speed of sound and the frequency of the sound that will be resonating in the open air column.

Applying the universal wave equation, the designer can determine the wavelength and then cut the pipe at the proper one-half wavelength interval. By making the pipe length an interval of one-half the wavelength, the designer is able to construct an organ that is suitably loud, without any need for electrical amplification. This fact, among many others, is why organs were extensively used in churches that were designed long before electrical amplifiers.

Add varying amounts of water to the empty bottle that you had at the beginning of this lesson, and observe the change in pitch (frequency) of the note produced when you blow across the bottle. Obtain a second bottle with a narrow neck, and, with another student if possible, use water levels to "tune" both bottles to the same frequency. You may be able to produce a sound regardless of the amount of water in the bottle, so listen carefully for that clear, loud tone and adjust the water as needed.

Module 8: Lesson 4 Assignment

Remember to submit the answer to Discuss to your teacher as part of your Lesson 4 Assignment.

Discuss

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A wind instrument, such as a flute or clarinet, is designed in such a way that the length of the air column can effectively be changed by opening and closing holes in the instrument. The resonant frequency that will be heard from such instruments is produced by a wave that is twice as long as the distance between the mouthpiece and the first open hole in the instrument. This wave is known as the fundamental frequency. However, an instrument will produce its own unique sound even if it has the same fundamental frequency as another type of instrument. For example, a flute and a clarinet could have the same air column length, producing the same fundamental frequency, but they don't sound the same. Why? They have different timbre or tone colour, the quality that allows you to distinguish different instruments even if they play the same note.

In the discussion forum, explain why these instruments must be an open air column. Using page 423 of your textbook as a source, explain how overtones give each wind instrument a unique sound even though they may resonate with the same fundamental frequency.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module deal with waves and transferring energy. To reinforce your learning from this lesson, complete at least one of the following reflection activities:

- Do a quick survey of three or four friends who are not taking physics. Find out from them what they think determines the pitch of a flute or clarinet. When you have your friends' opinions, summarize their ideas into two categories: misconceptions and facts. Explain why items are in each column.
- Have you heard a live performance on a pipe organ or a recording with a pipe organ on it? Does the volume of sound coming from simple pipes and moving air surprise you? Create a drawing or a multimedia presentation that helps explain how something so simple can be so loud.

Store your completed reflection in your Physics 20 course folder.

Module 8: Lesson 4 Assignment

Make sure you have completed all of the questions for the Lesson 4 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 8 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have developed answers to these questions:

- How is a standing wave produced in a closed-air column?
- What is the relationship between wavelength and air column length for a closed resonating air column?
- How is a standing wave produced in an open-air column?
- What is the relationship between wavelength and air column length for an open resonating air column?

A sound wave will travel through a closed-air column until it reaches the closed end, where it is reflected. The reflected wave will encounter other incoming waves, and interference will occur to produce a standing wave pattern. The closed end of the air column serves as a fixed point (node), with alternating points of complete destructive interference (nodes) and points of complete constructive interference (antinodes) extending towards the open end of the air column.

A closed-air column will only resonate when an antinode is located at the open end. This is observed as an increase in volume when both the air column and the sound source (tuning fork) are producing identical sound waves. This occurs when the air column length (L) is $\frac{1}{4}, \frac{3}{4}, \frac{5}{4}, \cdots$ times the length of the standing wave (λ).

An open-air column will hold a standing wave in a similar way to that of a closed-air column. Alternating points of complete destructive interference (nodes) with points of complete constructive interference (antinodes) extend throughout the air column.

An open-air column will only resonate when an antinode is located at both open ends. This is observed as an increase in volume when both the air column and the sound source (tuning fork) are producing identical sound waves. This occurs when the air column length (L) is $\frac{1}{2}, \frac{2}{2}, \frac{3}{2}, \cdots$ times the length of the standing wave (λ).

Lesson 5—Two-Point Interference Patterns

Get Focused


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The home entertainment system delivers both a visual and audio experience for the user. Usually, the visual part of the system is set up directly in front of the user. Typically, the audio is delivered via a set of speakers, ranging from two to dozens of speakers found in various locations relative to the user. In this photo, the speakers are placed on either side of the screen. In this kind of setup, there will be certain spots in the room where the sound quality is excellent; in other spots, it will be poor. Why is this? How could you predict where the good listening spots are going to be?

The two speakers can be thought of as two point sources of sound waves. If the speakers produce identical, constant tones, and you were to slowly move around the room, you would notice that the volume of the sound changes.

You may have already guessed that interference between the identical sound waves produced by each speaker will produce a pattern of interference throughout the room. As in any interference pattern, there will be points of maximum constructive interference and points of maximum destructive interference. These points will be observed with high and low volumes of sound when the speakers are emitting identical sound waves. How can you predict where these points will be? Do you need to consider the interference pattern when designing a home entertainment room? Is it possible to reduce the amount of sound interference in the entertainment room? If so, how is it possible?

As you work through this lesson, keep the following questions in mind:

- What is path length and path difference?
- What is the relationship between path difference and constructive/destructive interference?
- What are nodal and antinodal lines?

Module 8: Lesson 5 Assignments

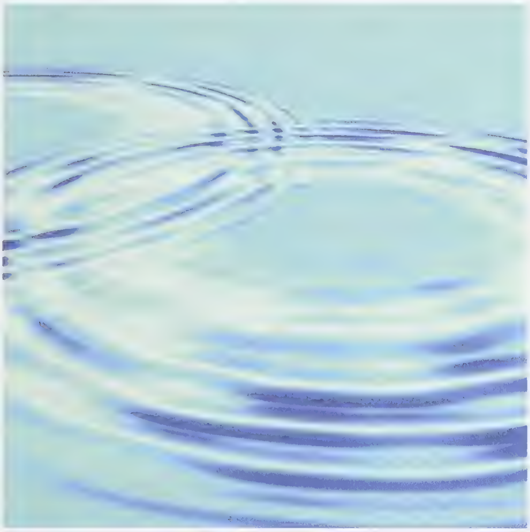
Your Lesson 5 Assignment in the Module 8 Assignment Booklet requires you to submit a response to the following:

- Try This—TR 1, TR 2, and TR 3
- Lab—LAB 1

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore



© Jenny Solomon/shutterstock

Although sound waves are longitudinal waves, they will be represented as transverse waves for the purposes of illustration. In this sense, sound waves behave in a similar way to water waves, as seen in the photo to the right. Imagine two point sources that produce identical waves that run into one another. Recall from previous lessons that when two wave fronts meet, they combine according to the principle of superposition (the displacement of a given particle is equal to the sum of the displacements that would have been produced by each wave acting independently). The waves combine in three possible ways—constructively (in phase), destructively (out of phase), or somewhere in between (intermediate).

Watch and Listen

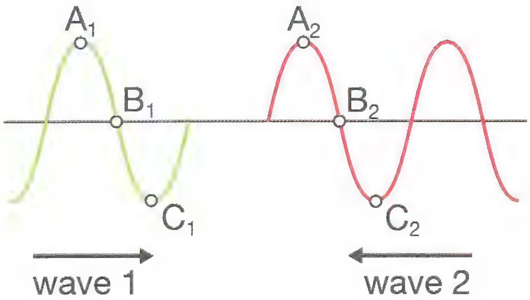
Go to your Physics 20 Multimedia DVD, and watch the "Interference" video clip to observe the interference pattern produced by two point sources.

Module 8: Lesson 5 Assignment

Remember to submit the answer to TR 1 to your teacher as part of your Lesson 5 Assignment.

Try This

TR 1. The diagram below shows two waves moving towards each other. For each of the following combinations, circle whether the interference will be constructive (C), destructive (D), or intermediate (I). For example, when point A_1 meets point C_2, the wave will destructively interfere, producing no amplitude.



a. A_1 and A_2	C	D	I	e. B_1 and C_2	C	D	I
b. A_1 and B_2	C	D	I	f. C_1 and A_2	C	D	I
c. A_1 and C_2	C	D	I	g. C_1 and B_2	C	D	I
d. B_1 and A_2	C	D	I	h. C_1 and C_2	C	D	I

You answered TR 1 using the concept that interference depends on the phase relationship between waves. You can think of the phase relationship in terms of **path difference**. To reach a common point, the wave fronts must each travel a certain **path length**, L. When two wave paths are compared and are found to travel different lengths, then a path difference, ΔL, exists. You will use a simulation to investigate how path difference relates to interference.

path difference: the difference between two path lengths

path length: the distance between a source and an observer

Lesson 5 Lab: Path Difference and Interference

Go to **www.learnalberta.ca**. You may be required to input a username and password. Contact your teacher for this information. Enter the search term "interference" in the search bar. Choose the item called "Interference and Huygens' Principle." The applet used for this lab lets you simulate wave motion and interference in a ripple tank. You will explore the concepts of path difference and Huygens' Principle. You can learn more about the simulation and how to use it by reading the Show Me found at the top of the simulation screen.

Problem

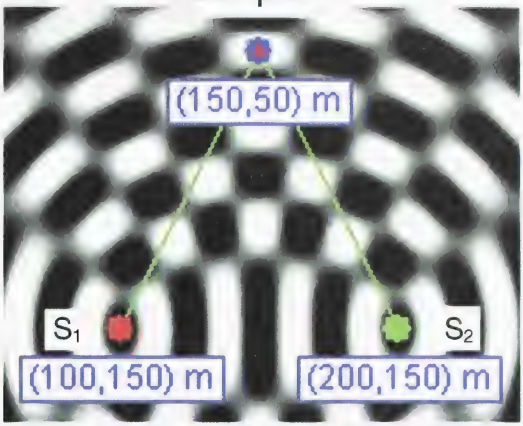
What is the relationship between path difference and interference?

Procedure

The figure to the right shows two point sources (S_1 and S_2) producing circular waves that interfere with one another. Set up this situation on the simulator by doing the following:

- Reset the display ( ).
- Click once anywhere in the display panel to add a wave source.
- Display the source coordinates by selecting "Show Coords" (☑Show Coords.).
- Click and drag source 1 (S_1) to coordinate (100, 150). If you accidentally add another source, you can remove it by clicking the minus symbol ( ).
- Add another source by clicking anywhere in the display panel.
- Click and drag source 2 (S_2) to coordinate (200, 150).
- Add the test point by selecting "Path Diff." (☑Path Diff.).
- Move the purple test point to coordinate (150, 50).
- Press "Play," and observe the interference pattern.

test point



Observations

Self-Check

SC 1.

a. Based on the figure titled "Test Point," is the length between S_1 and the test point identical to the length between S_2 and the test point? If so, is there a path difference?

b. Given the path difference from SC 1.a., predict the type of interference that occurs at the test point.

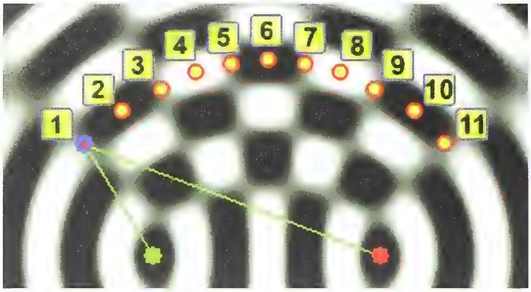
c. When the simulation is playing, what do you notice about the waves passing the test point?

Check your work with the answer in the appendix.

Module 8: Lesson 5 Assignment

Remember to submit the answers to LAB 1, LAB 2, LAB 3, and LAB 4 to your teacher as part of your Lesson 5 Assignment.

The following figure shows the interference pattern produced by two wave sources.



Set up a similar wave pattern on the simulation by setting the resolution at 10.0 and selecting a wavelength of 30.0 m. On the simulation, systematically position the test point at each at each of the first six numbered positions in turn.

LAB 1. Complete the following table.

Number	Type of Interference	Path Difference (Number of Wavelengths)
1	destructive	2.5
2		
3		
4		
5		
6		

a. In the right column, record the path difference that is displayed in the upper left corner of the display. Note that the simulation displays the path difference in terms of the number of wavelengths or waves.

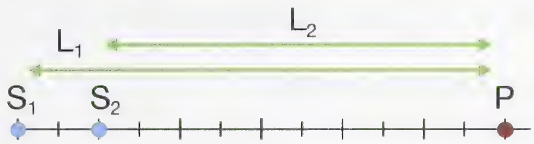
b. In the left column, list the type of interference at each point and the path difference. The simulation shows destructive interference as grey, while constructive interference alternates between white and black as seen when you press "Play." The first row is done for you.

LAB 2. Based on your recorded observations on the table, describe the connection between the interference type and path difference.

LAB 3. Using the principle of superposition, explain the relationship between constructive interference and path difference. Include a diagram with your answer.

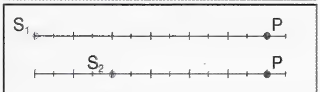
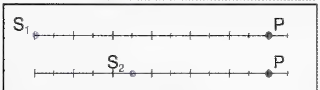
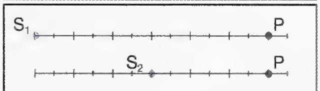
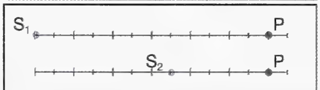
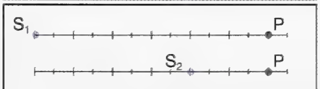
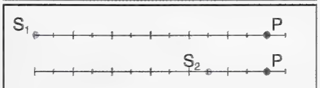
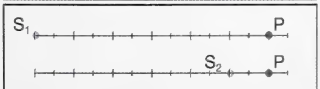
LAB 4. Using the principle of superposition, explain the relationship between destructive interference and path difference. Include a diagram with your answer.

The following figure shows two sources (S_1 and S_2) that emit waves. The waves are identical ($\lambda = 1.0$ m) and are emitted in phase. A detector (P) is located 6.0 m away from S_1. Initially, the sources are separated by 1.0 m; however, S_2 is systematically moved closer to the detector in increments of 0.5 m.



Self-Check

SC 2. Complete the following table. L_1 and L_2 represent the path length from S_1 to P and S_2 to P, respectively. For the wave diagram, sketch in the waves emitted by each source—this will help you determine the type of interference. The first row is completed for you. Here is a printable copy of the following table.

L_1 (m)	**L_2 (m)**	**λ (m)**	**$\frac{\Delta L}{\lambda}$**	**Wave Diagram**	**Type of Interference**
6.0	5.0	1.0	1		constructive
					
					
					
					
					
					
					
					

SC 3.

a. What is the relationship between $\frac{\Delta L}{\lambda}$ and constructive interference?

b. What is the relationship between $\frac{\Delta L}{\lambda}$ and destructive interference?

Check your work with the answer in the appendix.

Conclusion

Self-Check

SC 4.

a. For constructive interference to occur, the waves must arrive __________. The path difference must be a ________________ of waves.

b. For destructive interference, the waves must be ______________. The path difference is a ________________ waves.

c. Express these two conditions mathematically. ΔL is path difference, λ is the wavelength, and n is the number of waves.

Check your work with the answer in the appendix.

Module 8: Lesson 5 Assignment

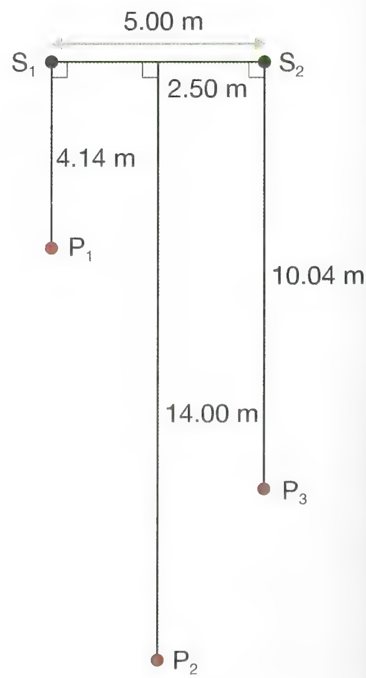
Remember to submit the answer to TR 2 to your teacher as part of your Lesson 5 Assignment.

Try This

TR 2. Two speakers (S_1 and S_2) are separated by 5.00 m and emit sound waves in all directions with $f = 440$ Hz. Three people (P_1, P_2, and P_3) are located at different distances from the speakers, as shown.

a. Using the universal wave equation ($v = f\lambda$), determine the wavelength emitted by the speakers when the speed of sound is 345 m/s.

b. Complete the following table. L_1 and L_2 represent the path's length from S_1 and S_2 to the person, respectively. They must be calculated using trigonometry and the data in the figure.



	To P_1 (m)	To P_2 (m)	To P_3 (m)
L_1 (m)			
L_2 (m)			
ΔL (m)			
$\frac{\Delta L}{\lambda}$			
Type of Interference			

c. What is the pattern between $\frac{\Delta L}{\lambda}$ and constructive interference?

d. What is the pattern between $\frac{\Delta L}{\lambda}$ and destructive interference?

e. Do the three people all hear the same thing? Why or why not?

For constructive interference to occur, the waves must arrive in phase—the path difference must be a whole number of wave lengths. Expressed mathematically, it is

$$\Delta L = n\lambda \qquad n = 0, \pm 1, \pm 2, ...$$

For destructive interference, the waves must be out of phase—the path difference is offset by half a wave length. Expressed mathematically, it is

$$\Delta L = \left(n + \frac{1}{2}\right)\lambda \qquad n = 0, \pm 1, \pm 2, ...$$

ΔL is path difference, λ is the wavelength, and n is number of waves.

Antinodal and Nodal Lines

In the previous section, you discovered the relationship between path difference and interference. Interference patterns can be quite complex, but they really just consist of regions of constructive and destructive interference. As such, interference patterns form lines.

Antinodal lines are lines that depict regions of full constructive interference (alternating bright and dark regions on the simulation).

Nodal lines refer to regions where the interference is destructive (grey regions on the simulation).

antinodal line: areas of full constructive interference

nodal line: areas of full destructive interference

Self-Check

SC 5. On the following diagrams, sketch the nodal lines on Figure A and the antinodal lines on Figure B. If you need some help, use the "Interference and Huygens' Principle" applet. Set up a similar series of wave sources and, using the path difference option, determine the type of interference.

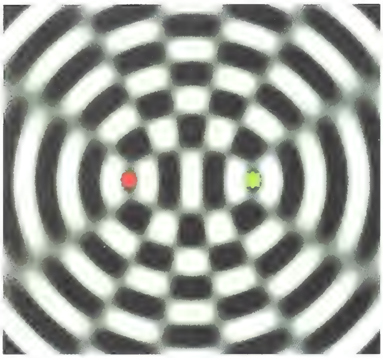


Figure A

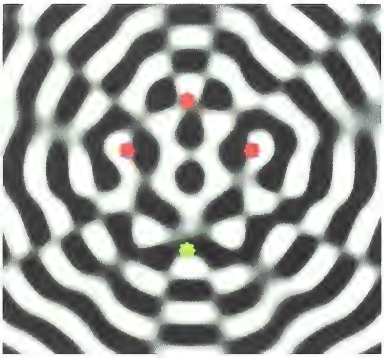


Figure B

Check your work with the answer in the appendix.

Module 8: Lesson 5 Assignment

Remember to submit the answer to TR 3 to your teacher as part of your Lesson 5 Assignment.

Try This

TR 3. Imagine that the images in SC 4 depict the surface of a pond. Describe the motion of a water beetle on the surface of the water when it is located at each of the following locations:

a. along a nodal line
b. along an antinodal line

Interference patterns can be mesmerizing and hypnotic! Spend some time playing with the simulation, and come up with a variety of different patterns.

Read

Read "An Interference Pattern from Two In-phase Point Sources" on pages 425 to 427 of your textbook.

Self-Check

SC 6. Complete question 8 of "8.3 Check and Reflect" on page 428 of your textbook.

Check your work with the answer in the appendix.

Reflect and Connect

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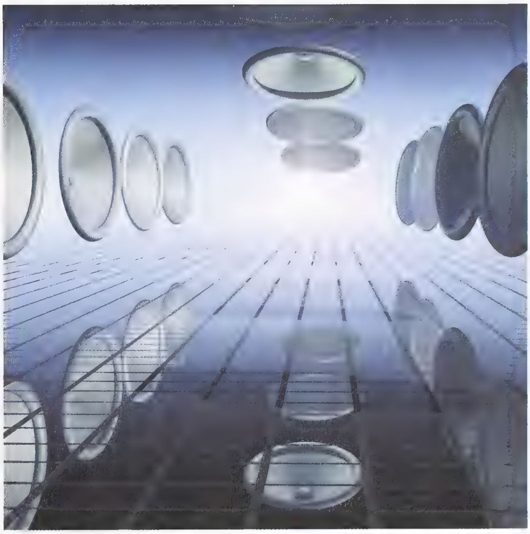
When two speakers are located near one another, and they each continually emit identical sound waves that are in phase, the principle of superposition will apply wherever the wave fronts meet. This produces an interference pattern with nodal lines and antinodal lines. The nodal lines are areas of destructive interference, where the medium appears undisturbed. Along these lines, the volume of sound will be very low because the waves are out of phase, causing destructive interference. Along the antinodal lines, the volume of sound will be very high because the waves are in phase, causing constructive interference. Determining the difference in path length between the observer and each speaker, in terms of the wavelength being emitted, would allow you to predict what kind of interference will occur at the observer's position. These interference effects can be applied in the design and layout of the sound system in an entertainment room.

Discuss

Interference effects are generally considered to have a negative impact on the quality of sound produced by speakers. For example, both the Jubilee Auditoriums in Calgary and in Edmonton were renovated to reduce the interference at several "hot" and "cold" spots in the seating areas. This involved moving sound-reflecting surfaces, sound-absorbing surfaces, or the location of the seats.



© Dan Collier/shutterstock

If it's possible to physically accommodate interference, could it not be used to eliminate unwanted sounds? For example, could the principle of superposition be used to destroy undesirable sound waves? Consider the interior of a car with a known configuration of speakers, such as those shown in the photo.

When the car is being driven, it produces sounds from the moving tires and vibrations from the engine and other moving components. Research the idea of using speaker placement in a car to minimize background noise. In the discussion forum, propose a method in one paragraph to eliminate background noise in a vehicle by using the vehicle's sound speakers.

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module deal with waves and transferring energy. To help reinforce your learning from this lesson, complete at least one of the following reflection activities:

- Rogue waves are relatively large, spontaneous waves that occur in the ocean. They were once considered to exist only in legends, but scientists have proof that they are a naturally occurring phenomenon. There are numerous possible causes of rogue waves that are currently being researched, and one theory involves constructive interference. Explain how this could cause rogue waves. Research two other possible causes of rogue waves.

- Imagine that you work in a store that rents sound equipment for outdoor events, such as concerts and block parties. You want to be able to clearly explain to your customers how to best set up the equipment to minimize interference patterns. Create an analogy for wave interference using a sport to explain appropriate equipment placement. Try to use your favourite sport, but if you don't have one, hockey should work.

- Think about what you would consider an ideal surround-sound system. Describe your system, and explain how you would minimize destructive interference in setting it up.

Store your completed reflection in your Physics 20 course folder.

Module 8: Lesson 5 Assignment

Make sure you have completed all of the questions for the Lesson 5 Assignment. Check with your teacher about whether you should submit your assignment now or wait until all of the Module 8 assignments have been completed.

Lesson Summary

As you worked through this lesson, you should have developed partial answers to these questions:

- What is path length and path difference?

- What is the relationship between path difference and constructive/destructive interference?

- What are nodal and antinodal lines?

Interference depends on the phase relationship between waves, described in terms of path difference. To reach a common point, the wave fronts must each travel a certain path length, L. When two wave paths are compared and are found to travel different lengths, a path difference, ΔL, exists. The difference in path length is measured in terms of the wavelength of the waves produced by each source.

For constructive interference to occur, the waves must arrive in phase—the path difference must be a whole number of waves. For destructive interference, the waves must be out of phase—the path difference is offset by half a wave. These two conditions can be expressed mathematically. ΔL is path difference, λ is the wavelength, and n is the number of waves.

Constructive Interference	$\Delta L = n\lambda \qquad n = 0, \pm 1, \pm 2, ...$
Destructive Interference	$\Delta L = \left(n + \frac{1}{2}\right)\lambda \qquad n = 0, \pm 1, \pm 2, ...$

Interference patterns consist of regions of constructive and destructive interference. As such, interference patterns form lines.

Antinodal lines are regions of full constructive interference. Nodal lines are regions of full destructive interference.

Lesson Glossary

antinodal line: areas of full constructive interference

nodal line: areas of full destructive interference

path difference: the difference between two path lengths

path length: the distance between a source and an observer

Lesson 6—The Doppler Effect

Get Focused

US Navy photo by Ensign John Gay

The plane in this photo is travelling near the speed of sound. Just as a boat moving through water produces a bow wave, the plane will produce a bow wave as it moves through the air. Normally, the bow waves propagate outward in a V-shape behind the object that is producing them. However, in this case, the plane is travelling as fast as the bow waves (the speed of sound). When this occurs, the bow waves start to "pile up" or store energy, creating what is known as a sonic boom.

In a sonic boom, the leading pressure waves produced by the plane are compressed, forming a shock wave that is seen in the photograph as compressed water vapour in the form of a cloud. The wavelength of the bow waves change, depending on how fast the object producing them is moving. You may have observed this with your ears when a fast-moving object, such as a plane, train, or race car, passes by. The sound it makes as it approaches you is different in frequency and wavelength than the sound it makes once it has passed by. This is called the Doppler effect, and it is also responsible for producing a sonic boom. Why does the frequency of the sound waves change when the source producing them moves? What is the relationship between the speed of sound, its frequency, and its wavelength? How are these relationships described mathematically by the Doppler equation?

As you work through this lesson, keep the following questions in mind:

- What happens to the wavelength and frequency of sound that is produced by a moving source?

- How does the Doppler equation describe the frequency observed by a moving sound source?

Module 8: Lesson 6 Assignments

Your Lesson 6 Assignment in the Module 8 Assignment Booklet requires you to submit a response to the following:

- Try This—TR 1, TR 2, TR 3, TR 4, TR 5, and TR 6
- Discuss—D 1, D 2, D 3, and D 4

You must decide what to do with the questions that are not marked by the teacher.

Remember that these questions provide you with the practice and feedback that you need to successfully complete this course. You should respond to all the questions and place those answers in your course folder.

Explore

Recall that for a mechanical wave, such as sound, the universal wave equation gives the relationship between frequency, wavelength, and speed.

$v = f\lambda$

© Norebbo/shutterstock

The speed of sound in air varies according to temperature and pressure. If temperature and pressure are constant, the speed of sound is also constant. If you know the speed of sound, the observed frequency of a given wavelength can be derived through a simple application of the universal wave equation. For example, when the speed of sound is 350 m/s, a 1.75-m wave will produce a tone of 200 Hz.

$$v = f\lambda$$
$$f = \frac{v}{\lambda}$$
$$f = \frac{(350 \text{ m/s})}{1.75 \text{ m}}$$
$$f = 200 \text{ Hz, correct to 3 significant digits}$$

According to this calculation, if the wavelength were to change, the observed frequency would also change. But how would the wavelength change if the object producing it were to start moving?

Wavelength and Frequency of a Moving Source

Go to your Physics 20 Multimedia DVD, and choose the item called "Moving Point Source." This simulation will be used to explore what happens to the wavelength of sound when the source of the sound is moving.

Module 8: Lesson 6 Assignment

Remember to submit the answers to TR 1, TR 2, and TR 3 to your teacher as part of your Lesson 6 Assignment.

TR 1. Play the simulation by pressing “Start.” Observe the wave fronts produced by the moving object. Recall that wavelength is the distance between each front.

a. On which side of the object are the waves compressed?
b. Why do they appear compressed only on this side?

TR 2. Reset the simulation, and increase the source speed by dragging out the respective vector arrow. What happens to the leading wavelength as the speed of the source increases?

TR 3. Reset the simulation, and set the source speed to be equal to the speed of sound.

a. What is the wavelength of the sound in front of the source when it is travelling at the speed of sound?

b. What special name is given to the single wave front when this happens?

According to the universal wave equation, if the wavelength is reduced while the speed of sound remains unchanged, the frequency will increase. Imagine that you are standing stationary and a moving sound source approaches. When the sound source is moving, the leading wave fronts are compressed. According to the universal wave equation the shortened wavelength will produce a higher frequency sound as it approaches a stationary observer. At the same time, the trailing wave fronts are stretched and the longer wavelength produces a lower frequency sound as the source moves past and away from the observer.

Read

To clarify this concept, read pages 429 and 430 of your physics textbook. Stop at the heading “Analysis of the Doppler Effect.”

The Doppler Equation

If a sound source is moving towards you (the observer), the wavelength is compressed a distance equal to the amount of distance the source moves during the time it takes to produce one full wave. Considering this fact, and using previous definitions for uniform motion ($v = d/t$) and period ($T = 1/f$), the **Doppler effect** can be described as the following equation:

$$f_d = \left(\frac{v_w}{v_w \pm v_s} \right) f_s$$

Doppler effect: the observed change in frequency and wavelength of a wave produced by a source moving relative to an observer

Quantity	Symbol	SI Unit
Doppler frequency (observed)	f_d	Hz
source frequency	f_s	Hz
wave velocity	v_w	m/s
source velocity	v_s	m/s

When the source is moving *towards* the stationary observer, the equation produces a higher observed frequency than the source frequency. The equation is as follows:

$$f_d = \left(\frac{v_w}{v_w - v_s} \right) f_s$$

When the source is moving *away* from the stationary observers, the equation produces a lower observed frequency than the source frequency. The equation is as follows:

$$f_d = \left(\frac{v_w}{v_w + v_s}\right) f_s$$

Read

How is this formula applied? Read "Analysis of the Doppler Effect" starting from the bottom of page 430 to the bottom of page 432 of your textbook.

Self-Check

SC 1. Complete question 1 of "Practice Problems" on page 432 of your textbook.

Check your work with the answer in the appendix.

Module 8: Lesson 6 Assignment

Remember to submit the answers to TR 4, TR 5, and TR 6 to your teacher as part of your Lesson 6 Assignment.

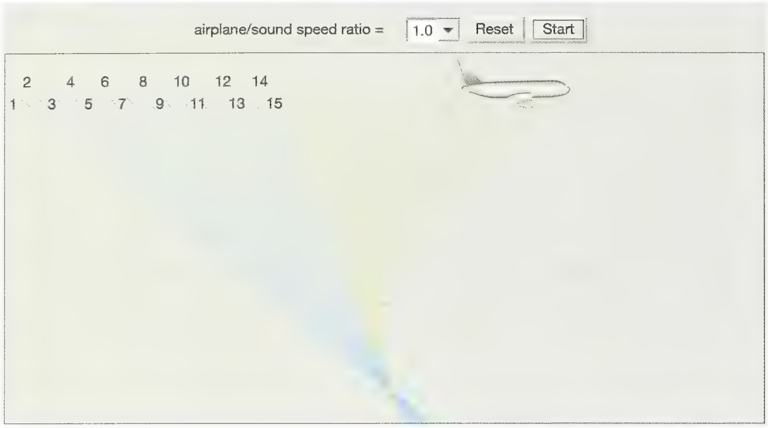
Try This

TR 4. A fire engine is being driven away from you at a speed of 15.4 m/s. One of the notes in its siren sequence has a fundamental frequency of 244 Hz. If the speed of sound is 338 m/s, what will seem to you to be the fundamental frequency of that particular note?

TR 5. An automobile is approaching you at a speed of 50.0 km/h and sounding its horn. The fundamental frequency of the horn sounds to you like 266 Hz. If the speed of sound is 335 m/s, what is the real fundamental frequency of the horn?

TR 6. An automobile is approaching you at a speed of 90.0 km/h and sounding its horn. The fundamental frequency of the horn sounds to you like 268 Hz. If the real fundamental frequency of the horn is 248 Hz, what is the speed of sound?

Reflect and Connect



If an airplane is travelling faster than the speed of sound and it passes overhead, you will hear a sonic boom. Will the plane have passed by before you hear the boom?

When a sound source, such as an airplane, travels at the speed of sound, the emitted sound waves travel at the same speed as the object producing them. This causes the waves to pile up and store energy in the form of a shock wave.

Because all the sound waves travel at the same speed in the air (based on constant temperature and pressure), it is easy to predict where the plane will be when the shock wave reaches the observer. Go to your Physics 20 Multimedia DVD, and use the simulation called "Supersonic Airplane" to explore this concept. Scroll the browser window to the bottom to see the directions on how to use the simulation. Be sure to click the "Reset" button after you have changed the speed to sound ratio.

Module 8: Lesson 6 Assignment

Remember to submit the answers to D 1, D 2, D 3, and D 4 to your teacher as part of your Lesson 6 Assignment.

Discuss

Police use radar (radio detection and ranging) to determine the speed of vehicles on the roadways. The same type of radar is used to measure puck and ball speeds in sports. Research how this technology is related to the Doppler effect, and post a response to the following questions:

D 1. How does radar work?

D 2. What assumptions are made about radio waves in relation to mechanical waves such as sound?

D 3. How does a radar detector work?

D 4. Would a police radar gun work correctly even when the police car is in motion? Explain.

© Brad Sauter/shutterstock

Reflect on the Big Picture

Each of the Reflect on the Big Picture sections in this module deals with waves and transferring energy. To help reinforce your learning from this lesson, complete at least one of the following reflection activities:

- Sound that is above the hearing range is known as ultrasound. Do some quick research to see how the Doppler effect is used in medical ultrasound units.

- You've looked at many examples of sound waves. Now think about light waves. They also appear to change length if the source is moving toward or away from you. Create a drawing in a science-fiction style that incorporates this wavelength change.

Store your completed reflection in your Physics 20 course folder.

Complete the concept map under the heading "Conceptual Overview" on page 435 of your textbook, and store it in your Physics 20 course folder.

Module 8: Lesson 6 Assignment

Remember to submit the Module 8 Assignment Booklet to your teacher.

Lesson Summary

As you worked through this lesson, you should have developed partial answers to the following questions:

- What happens to the wavelength and frequency of sound that is produced by a moving source?

- How does the Doppler equation describe the frequency observed by a moving sound source?

When the sound source is moving, the leading wave fronts are compressed. According to the universal wave equation, the shortened wavelength will produce a higher frequency sound as it approaches a stationary observer. At the same time, the trailing wave fronts are stretched and the longer wavelength produces a lower frequency sound as the source moves past and away from the observer.

The Doppler effect is the observed change in frequency and wavelength of a wave produced by a moving source relative to an observer. Expressed as an equation, it is

$$f_d = \left(\frac{v_w}{v_w \pm v_s} \right) f_s$$

Quantity	Symbol	SI Unit
Doppler frequency (observed)	f_d	Hz
source frequency	f_s	Hz
wave velocity	v_w	m/s
source velocity	v_s	m/s

The wave and source velocities are subtracted when the source is moving towards the stationary observer. The velocities are added when the source is moving away from the stationary observer.

Lesson Glossary

Doppler effect: the observed change in frequency and wavelength of a wave produced by a source moving relative to an observer

Module Summary

In this module you looked for answers to these questions:
- How do mechanical waves transmit energy?
- How is structural design and development of technologies influenced by understanding of wave properties?

In this module you learned that a mechanical wave requires a medium, a source that disturbs the medium, and a way for adjacent parts of the medium to influence each other. Along with this, you saw that characteristics of waves, such as speed, frequency, wavelength, and amplitude, are needed to describe wave motion. Three of these characteristics are related by the universal wave equation, $v = f\lambda$.

You studied how waves interact with barriers or boundaries; and through this, you can better understand how satellite dishes concentrate signals. You learned that $\theta_{\text{incident}} = \theta_{\text{reflected}}$ when waves reflect. As well, you saw how the Huygens' Principle can help explain reflection.

You learned about constructive and destructive interference. You saw how waves can be combined and that the result changes as the phases of the waves change. You used the principle of superposition to combine waves. You studied standing waves and how the nodes of standing waves are distributed in vibrating strings half a wavelength apart.

You also studied how air columns resonate and how the wavelength and air column lengths are related. For a closed-air column to resonate, its length must be an odd multiple of a quarter of the standing wave's length $\left(\frac{1}{4}\lambda, \frac{3}{4}\lambda, \frac{5}{4}\lambda, \cdots\right)$. For an open-air column to resonate, the length must be a multiple of half of the standing wave's length $\left(\frac{1}{2}\lambda, \frac{2}{2}\lambda, \frac{3}{2}\lambda, \cdots\right)$.

You continued studying about wave interference, expanding your knowledge to include multiple sources of waves. You learned conditions that allow for nodal and antinodal lines to occur. The following table summarizes how the wavelength and the path length difference lead to constructive or destructive interference.

Constructive Interference	$\Delta L = n\lambda$	$n = 0, \pm 1, \pm 2, \cdots$
Destructive Interference	$\Delta L = \left(n + \frac{1}{2}\right)\lambda$	$n = 0, \pm 1, \pm 2, \cdots$

You also learned about the result of a moving sound source and how this Doppler effect changes what a stationary observer hears. The Doppler effect is the observed change in frequency and wavelength of a wave produced by a moving source relative to an observer. Expressed as an equation, it is

$$f_d = \left(\frac{v_w}{v_w \pm v_s}\right) f_s$$

Quantity	Symbol	SI Unit
Doppler frequency (observed)	f_d	Hz
source frequency	f_s	Hz
wave velocity	v_w	m/s
source velocity	v_s	m/s

The wave and source velocities are subtracted when the source is moving towards the stationary observer. The velocities are added when the source is moving away from the stationary observer.

Module 8 Assessment

The assessment for Module 8 consists of six (6) assignments:

- Module 8: Lesson 1 Assignment
- Module 8: Lesson 2 Assignment
- Module 8: Lesson 3 Assignment
- Module 8: Lesson 4 Assignment
- Module 8: Lesson 5 Assignment
- Module 8: Lesson 6 Assignment

Unit D Conclusion

In Module 7 you described oscillatory motion in terms of period and frequency. In your examination of simple harmonic motion, you learned that it is the motion of an object due to a restoring force that is directly proportional to and opposite of its displacement from an equilibrium position. You studied the relationships among displacement, acceleration, velocity, and time for the simple harmonic motion in a frictionless, horizontal mass-spring system; and you looked at these relationships in reference to pendulums. You were able to determine the relationships among kinetic, gravitational potential, and total mechanical energies of a mass executing simple harmonic motion. You were also able to calculate these energies. Finally, you examined mechanical resonance and its impact in the everyday world.

Throughout this module, you discovered many examples of oscillatory motion in the world around you. You began by looking at oscillatory motion present in insects, guitars, pianos, and weighted springs. You expanded your studies to include pendulums, clocks, and metronomes. Perhaps the most dramatic examples of oscillatory motion that you examined related to mechanical resonance. A positive application of mechanical resonance is the quartz watch. A negative, and potentially deadly, application was evident when you looked at the Tacoma Narrows Bridge incident.

In Module 8 you began by looking at mechanical waves as particles of a medium that are moving in simple harmonic motion. From there, you were able to compare and contrast energy transmission by matter that moves and by waves. You looked at the direction of the motion of the particles and how it compared to the direction of the propagation of the wave. You learned that this factor determined whether the wave was a longitudinal wave or a transverse wave. As you examined longitudinal and transverse waves, you learned the terminology that allowed you to better define and describe them. You looked at the relationship between the speed of a wave and the characteristics of the medium. You applied the universal wave equation to help solve problems, and you examined the effects of each variable in the equation. You looked at the reflections of waves, the conditions for constructive and destructive interference of waves, and the conditions for acoustic resonance. Finally, you analyzed the phenomenon called the Doppler effect.

Your studies in this module showed that when a wave is displaced from its equilibrium position, it stores elastic potential energy. That energy is transmitted through the medium by the sequential displacement of the medium as the wave pulse moves through it. Energy is thereby transferred through the medium without the transmission of matter. You have seen how the application of acoustic phenomena in medicine, industry, and technology has provided many positive solutions to practical problems. You have learned about the destructive forces of waves and their implications for structural design.

Unit D Assessment

Answer the following questions, and submit your answers to your teacher for marks.

1. An object suspended from a spring with a spring constant of 2.56 N/m vibrates with a frequency of 0.148 Hz.

    a. What is the mass of the object?

    b. What will be the acceleration of the object at a displacement of –0.120 m from the equilibrium position?

2.
    a. What length of a 0.250-kg pendulum would be needed to oscillate at the same frequency as the object in question 1?

    b. What would be the restoring force on the pendulum at an angle of 6.24° from the equilibrium position?

    c. The pendulum is pulled aside until it is 0.386 m above its lowest position and released. The pendulum is designed to emit sound waves at a frequency of 440 Hz; however, as it swings toward and away from an observer, the frequency appears to vary slightly. What is this phenomenon called? What would be the apparent frequency of the sound from the pendulum as it swings at its maximum speed toward an observer? Assume the speed of sound is 345 m/s.

Module 8 Glossary

amplitude: the measure of the maximum displacement of a wave from the equilibrium position

angle of incidence (θ_i): the angle that an incident ray makes with the normal line

angle of reflection (θ_r): the angle that a reflected ray makes with the normal line

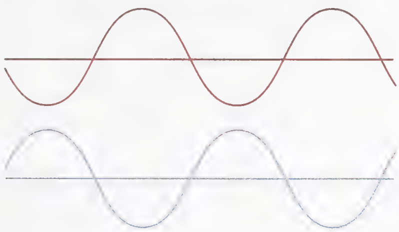
antinodal line: areas of full constructive interference

antinode: a place on a standing wave with maximal amplitude

constructive wave interference: overlapping of waves so the crests match with crests and troughs match with troughs

crest: the highest point in a wave

destructive wave interference: overlapping of waves so crests match with troughs



Doppler effect: the observed change in frequency and wavelength of a wave produced by a source moving relative to an observer

equilibrium position: the position where the medium would normally rest

incident ray: the ray that depicts the direction of the wave front that is moving from the point of origin toward the barrier

longitudinal wave: a wave in which the medium moves in the same direction as the wave

medium: the substance that acts as a carrier for a wave

nodal line: areas of full destructive interference

node: a place on a standing wave with minimal amplitude

normal line: an imaginary line that is perpendicular to the boundary

path difference: the difference between two path lengths

path length: the distance between a source and an observer

phase shift: for two sine waves, the change in angle needed to change the first sine wave into the second

point source: a source that radiates waves as if it were a point

ray: a line perpendicular to the wave front depicting the direction the wave is moving

reflected ray: a ray that depicts the direction of the wave front moving away from the barrier

reflection: a change in direction when a wave strikes and bounces from a surface

resonant frequency: the frequency at which an object naturally vibrates

standing wave: a wave that appears not to be travelling (stays in a constant position)

transverse wave: a wave in which the medium moves at right angles to the direction of the wave

trough: the lowest point in a wave

universal wave equation: the speed of the wave is equal to the product of the wave frequency and the wavelength

wavelength: the distance between consecutive crests (or troughs)

wavelet: a secondary wave

Self-Check Answers

Lesson 1

SC 1. A wave ray is a line indicating the direction of motion of the wave front at the point where the ray intersects the wave front.

SC 2. The reflected wave appears to have originated from an imaginary point source exactly the same distance behind the barrier as the actual source is in front of it.

SC 3.

a. The reflected wave appears to have originated from an imaginary straight wave generator exactly the same distance behind the barrier as the actual source is in front of it.

b. The angle between the reflected wave front and the barrier will have the same value as the angle between the incident wave front and the barrier.

SC 4.

a. The red dot moves vertically up and down.
b. The wave moves horizontally to the right.
c. The medium moves perpendicular to the wave.

SC 5.

a. The red dot moves horizontally.

b. The wave moves horizontally, travelling in only one direction.

c. The wave travels the same amount of distance as the red dot in any time interval because they both move at the same speed. However, the wave travels in only one direction whereas the medium (red dot) travels back and forth.

d. The red dot moves back and forth, but the wave travels in only one direction.

SC 6.

a.

total distance dot travels (1 grid square = 10 m)	**140 m**
start time (s)	**5.0 s**
end time (s)	**13.0 s**
time elapsed (s)	**8.0 s**
average speed of dot (in m/s)	**18 m/s**

b. The medium is moving upwards at 18 m/s.

SC 7.

a.

initial position of first crest (1 grid square = 10 m)	**68 m**
final position of first crest (m)	**258 m (varies)**
total distance wave travels (m)	**190 m (varies)**
initial time (s)	**0.0 s**
time at end (s)	**33.0 s (varies)**
time elapsed (s)	**33.0 s (varies)**
average speed of wave (in m/s)	**5.76 m/s**

b. The wave is moving to the right at 5.76 m/s.

SC 8.

Given

$v = 3.60$ m/s
$l = 2.50$ m

Required

the time required to produce the pulse (t)

Analysis and Solution

Use the formula $v = \frac{\Delta d}{\Delta t}$ to find the time. The length (l) is equal to Δd.

$$v = \frac{\Delta d}{\Delta t}$$
$$\Delta t = \frac{\Delta d}{v}$$
$$\Delta t = \frac{l}{v}$$
$$\Delta t = \frac{2.50\text{ m}}{3.60\text{ m/s}}$$
$$\Delta t = 0.694\text{ s}$$

Paraphrase

The time required to produce the pulse is 0.694 s.

SC 9. The answers below for distance and time are sample answers and yours will probably be different. The values for speed, however, should be close to the ones below.

Wavelength (m)	Frequency (Hz)	Total Distance Wave Travels (1 grid square = 250 m)	Time Elapsed (s)	Speed of Wave (m/s)
40	0.25	1000	100.0	10.0
90	1.0	3600	40.0	90.0
50	1.3	1300	20.0	65.0
80	1.6	2450	19.0	129
75	0.8	2225	37.0	60.1

SC 10.

$$v = f\lambda$$
$$v = (40\text{ m})(0.25\text{ Hz})$$
$$v = 10\text{ m/s}$$

$$v = f\lambda$$
$$v = (80\text{ m})(1.6\text{ Hz})$$
$$v = 128\text{ m/s}$$
$$v = 1.3\times10^{2}\text{ m/s to 2 significant digits}$$

The speeds do match to 2 significant digits. This means you have verified the universal wave equation.

SC 11.

Given

$f = 440$ Hz
$v = 350$ m/s

Required

the length of the sound wave (λ)

Analysis and Solution

Use the universal wave equation to calculate the length.

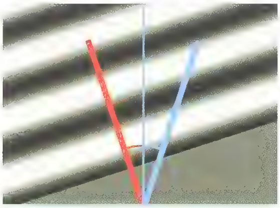
$$v = f\lambda$$
$$\lambda = \frac{v}{f}$$
$$\lambda = \frac{350 \text{ m/s}}{440 \text{ Hz}}$$
$$\lambda = 0.795 \text{ m}$$

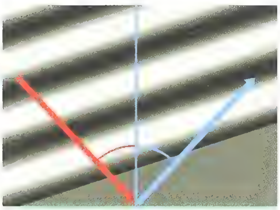
Paraphrase

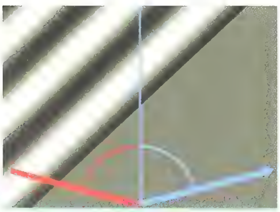
The length of the sound wave is 0.795 m.

Lesson 2

SC 1. The red arrow is the incident ray, and the blue line is the normal. The red angle is the angle of incidence.

a.

Incident angle = 18° ± 1°

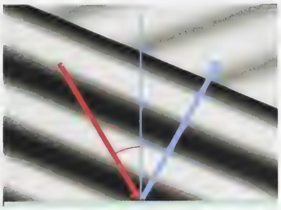
b.

Incident angle = 43° ± 1°

c.

Incident angle = 75° ± 1°

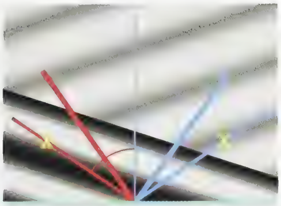
SC 2. The angle of incidence is equal to the angle of reflection in all cases.

SC 3.

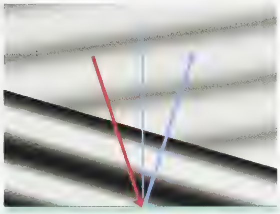
a. correct



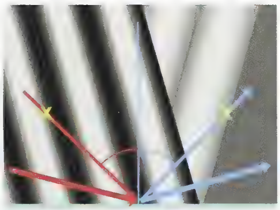
b. incorrect



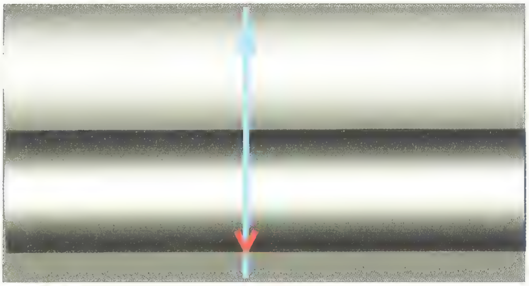
c. correct



d. incorrect

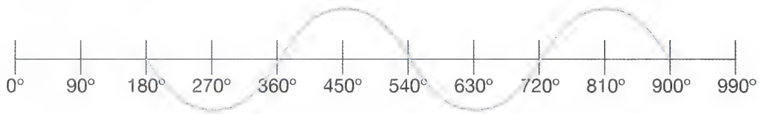


SC 4.



Lesson 3

SC 1. Your diagram should look like the following.



SC 2. Any odd multiple of π (3.14) radians causes complete destructive interference (e.g., 1π, 3π, −3π, 5π, −5π). The two conditions that must be met are

- the two waveforms have equal amplitude
- the two waveforms have equal wavelength

SC 3.

a. Maximum possible amplitude of the combined waves when they constructively interfere is 10 units + 20 units = 30 units.

b. Minimum amplitude of the combined waves when they destructively interfere is 20 units − 10 units = 10 units.

SC 4.

a. A node is a place where complete destructive interference continually occurs so there is no motion, and an antinode is a place where constructive interference occurs at the maximum displacement.

b. Nodes and antinodes are ¼ λ (one-quarter wavelength) apart.

Lesson 4

SC 1.

Given

$f = 256$ Hz
$v = 330$ m/s

Required

the length of the air column for the first four resonance positions (L_1, L_2, L_3, *and* L_4)

Analysis and Solution

The length of the air column for the first four resonance positions will occur at $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, $\frac{5}{4}\lambda$, and $\frac{7}{4}\lambda$.

$$L_1 = \frac{\lambda}{4}$$
$$\lambda = 4L_1$$
$$v = f\lambda$$
$$v = f(4L_1)$$
$$L_1 = \frac{v}{4f}$$
$$L_1 = \frac{330\ \text{m/s}}{4(256/\text{s})}$$
$$L_1 = 0.322\ \text{m}$$

$$L_2 = \frac{3\lambda}{4}$$
$$\lambda = \frac{4}{3}L_2$$
$$v = f\lambda$$
$$v = f\left(\frac{4}{3}L_2\right)$$
$$L_2 = \frac{3v}{4f}$$
$$L_2 = \frac{3(330\ \text{m/s})}{4(256/\text{s})}$$
$$L_2 = 0.967\ \text{m}$$

$$L_3 = \frac{5\lambda}{4}$$
$$\lambda = \frac{4}{5}L_3$$
$$v = f\lambda$$
$$v = f\left(\frac{4}{5}L_3\right)$$
$$L_3 = \frac{5v}{4f}$$
$$L_3 = \frac{5(330\ \text{m/s})}{4(256/\text{s})}$$
$$L_3 = 1.61\ \text{m}$$

$$L_4 = \frac{7\lambda}{4}$$
$$\lambda = \frac{4}{7}L_4$$
$$v = f\lambda$$
$$v = f\left(\frac{4}{7}L_4\right)$$
$$L_4 = \frac{7v}{4f}$$
$$L_4 = \frac{7(330\ \text{m/s})}{4(256/\text{s})}$$
$$L_4 = 2.26\ \text{m}$$

Paraphrase

The length of the air column for the first four resonance positions will occur at 0.322 m, 0.967 m, 1.61 m, and 2.26 m.

SC 2. Stringed instruments are tuned by adjusting the tension in the strings, but wind instruments are tuned by adjusting the length of the pipe.

SC 3.

a. $1\frac{1}{2}\lambda$ or $\frac{3}{2}\lambda$

b. $1\frac{3}{4}\lambda$ or $\frac{7}{4}\lambda$

Lesson 5

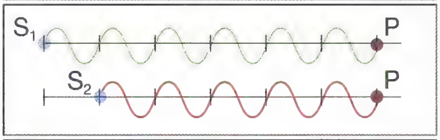
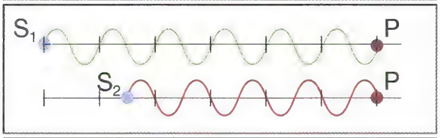
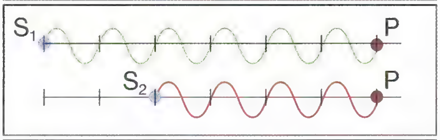
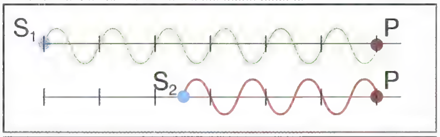
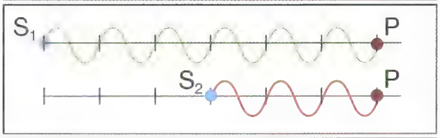
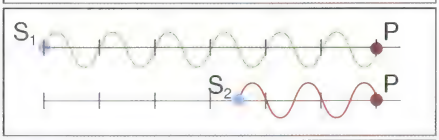
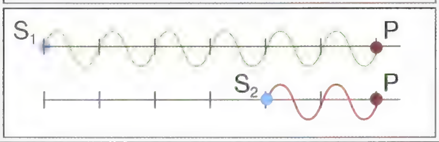
SC 1.

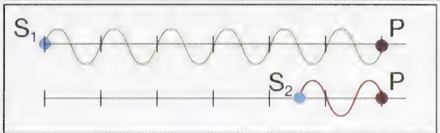
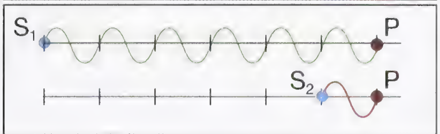
a. The lengths are identical, so there is no path difference. (The path difference is given in wavelengths at the top of the screen.)

b. Since the path length is identical, the waves will arrive in phase; therefore, constructive interference will occur.

c. The maximum amplitude waves (crests and troughs) pass through this point.

SC 2.

L_1 (m)	L_2 (m)	λ (m)	$\frac{\Delta L}{\lambda}$	Wave Diagram	Type of interference
6.0	5.0	1.0	1		constructive
6.0	4.5	1.5	1.5		destructive
6.0	4.0	2.0	2.0		constructive
6.0	3.5	2.5	2.5		destructive
6.0	3.0	3.0	3.0		constructive
6.0	2.5	3.5	3.5		destructive
6.0	2.0	4.0	4.0		constructive

6.0	1.5	4.5	4.5		destructive
6.0	1.0	5.0	5.0		constructive

SC 3.

a. Constructive interference occurs when $\frac{\Delta L}{\lambda}$ is a whole number.

b. Destructive interference occurs when $\frac{\Delta L}{\lambda}$ is a ½ a whole number.

SC 4.

a. For constructive interference to occur, the waves must arrive **in phase**. The path difference must be a **whole number** of waves.

b. For destructive interference, the waves must be **out of phase**. The path difference is a **half of a whole number of** waves.

c. Expressed mathematically, constructive interference is as follows:

$$\Delta L = n\lambda \qquad n = 0, \pm 1, \pm 2, \ldots$$

Expressed mathematically, destructive interference is as follows:

$$\Delta L = \left(n + \frac{1}{2}\right)\lambda \qquad n = 0, \pm 1, \pm 2, \ldots$$

SC 5.

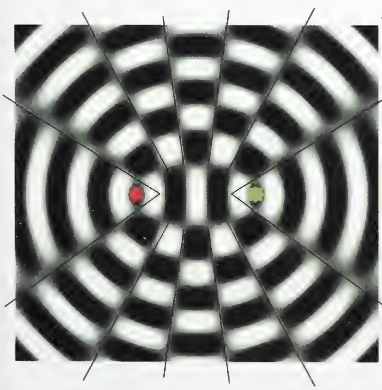


Figure A: nodal lines

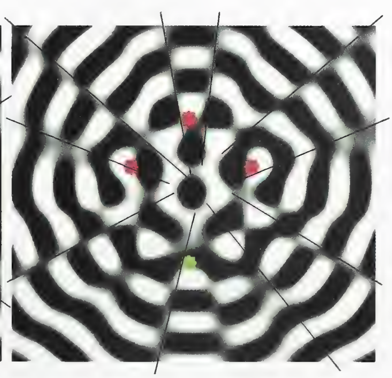
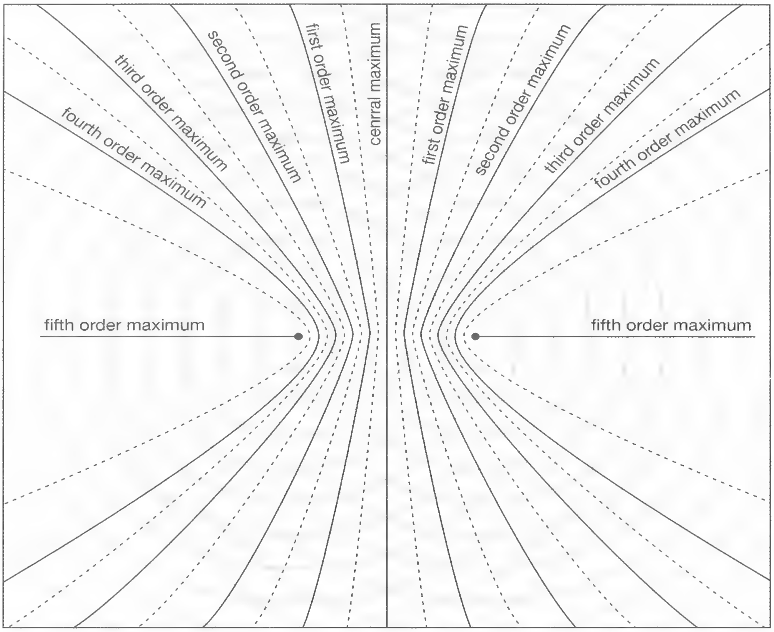


Figure B: antinodal lines

SC 6. There are five minima on each side of the central maximum because a minimum occurs whenever the difference in path length is equal to half an odd number times the wavelength. Thus, a minimum occurs at path length differences of 0.5 λ, 1.5 λ, 2.5 λ, 3.5 λ, and 4.5 λ. Five is the maximum number because the sources are separated by five wavelengths.



Lesson 6

SC 1.

Given

$f_s = 264$ Hz
$v_s = 60.0$ km/h
$v_w = 340$ m/s

Required

the apparent frequency of the horn (f_d)

Analysis and Solution

Convert the speed of the vehicle to m/s. Use the form of the Doppler effect equation for an approaching vehicle.

$$60.0\ \frac{\text{km}}{\text{h}} \times \frac{1000\ \text{m}}{1\ \text{km}} \times \frac{1\ \text{h}}{3600\text{s}} = 16.67\ \text{m/s}$$

$$f_{\text{d}} = \left(\frac{v_{\text{w}}}{v_{\text{w}} - v_{\text{s}}}\right) f_{\text{s}}$$

$$f_{\text{d}} = \left(\frac{340\ \text{m/s}}{(340\ \text{m/s}) - (16.67\ \text{m/s})}\right) 264\ \text{Hz}$$

$$f_{\text{d}} = 278\ \text{Hz}$$

Paraphrase

The apparent frequency of the horn is 278 Hz.